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REFERENCE

Lane, B. H., 1935, Suggestions to authors of papers submitted for publication by the United States Geological Survey: U. S. Geol. Survey, Washington, D. C. (For sale by Superintendent of Documents, Washington, D. C. 35c.)

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American Journal of Science

MAY 1954

THE SUB-EDEN BEDS OF THE OHIO VALLEY AROUND CINCINNATI

LAURENCE H. LATTMAN

ABSTRACT. This paper is based on a re-examination of the stratigraphy of the sub-Eden beds of Ordovician age along the Ohio River at its crossing of the Cincinnati arch. Review of the literature reveals several sources of confusion in nomenclature and correlation. A study of detailed sections at West Covington (at the western edge of Covington) and Carntown, Kentucky, and Point Pleasant, Ohio, has helped to clarify the highly confused and contradictory literature.

Two paleontologic zones have proved of great value in correlating the sub-Eden beds: the thin zone of *Escharopora ponderosa* (Ulrich) near the top of the terrane, and the zone of *Cryptolithus tesselatus* Green, which extends for about 35 feet below the Escharopora zone.

The Bromley shale seems to lack the characteristics of a useful stratigraphic unit, since it transgresses major faunal zones. It appears to be rather a discontinuous shaly facies of the Cynthiana formation.

The Rogers Gap formation, the uppermost member of the Mohawkian, and the overlying Fulton shales, the lowermost member of the Cincinnatian, are faunally indistinguishable in this area. They appear to be rather lithologic facies of the same time-rock unit.

The faunal and lithologic evidence strongly indicates the advisability of extending the Cincinnatian series downward to embrace the Cynthiana formation, rather than including this formation in the Mohawkian as has been the common practice.

INTRODUCTION

So much variation exists in the nomenclature and correlation of the sub-Eden beds of the Ohio Valley in the vicinity of Cincinnati that their position in the Cynthiana formation of Kentucky has not been firmly established to date. The term sub-Eden beds is used here rather than the more common name of Trenton of the Ohio Valley because the assignment of these strata to either the Trenton or the Cincinnatian series is still a moot question.

The base of the Cincinnatian series in the vicinity of Cincinnati is commonly drawn at the base of the Eden shales. The strata dealt with in this investigation crop out beneath the Eden shales in the banks of the Ohio River upstream from Cincinnati. These beds, consisting of alternating fossiliferous limestones and relatively unfossiliferous clay shales are present in three major exposures: West Covington to Ludlow, Kentucky; Carntown, Kentucky; and Point Pleasant, Ohio (fig. 1). This paper covers a detailed study of these three sections and the conclusions drawn therefrom.

Grateful acknowledgment is made to Dr. Kenneth E. Caster of the University of Cincinnati for his interest in, and guidance during, this investigation. Dr. Erwin Stumm and Dr. John A. Dorr, Jr. of the University of Michigan kindly read the manuscript and offered helpful suggestions.

SUMMARY OF THE LITERATURE ON THE SUB-EDEN BEDS

Ohio Valley.—The first investigator to apply names to the sub-Eden beds of the Ohio Valley was Orton (1873). He gave the name River Quarry beds to the 50 feet of rock exposed in the River Quarry section at West Covington and the name Point Pleasant beds to the lower 50 feet of the approximately 100 feet of rock exposed at Point Pleasant. He strongly implied, but did not specifically state, that he believed the upper 50 feet of the rocks exposed at Point Pleasant to be the equivalent of the River Quarry beds at West Coving-

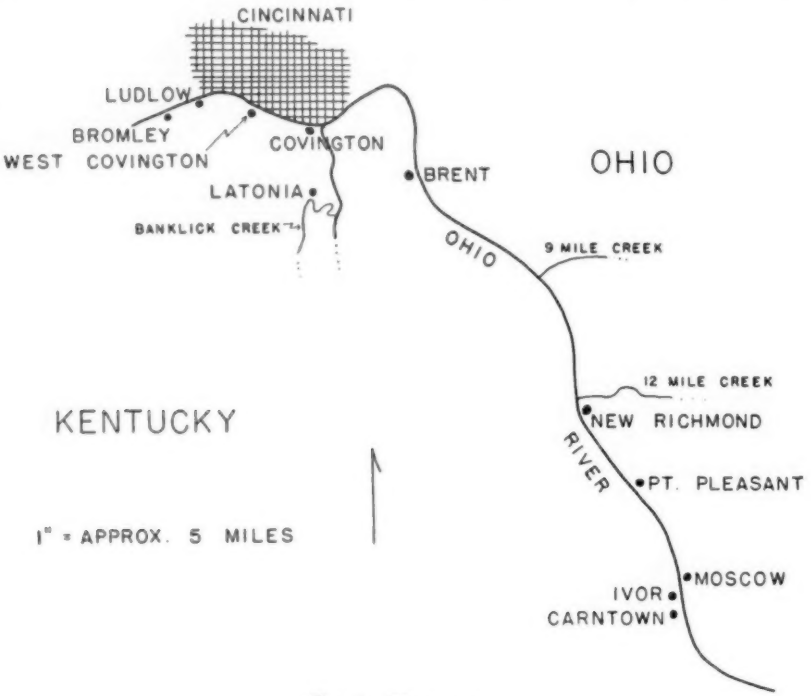

Fig. 1. Place map.

ton. Starting with Ulrich (1888), succeeding investigators differed widely in their use of Orton's names. The variation in application of Orton's nomenclature is shown on figure 2. In addition to Orton's names, three other major sets of names have been applied to the River Quarry section. These other names are shown on figure 3.

The sub-Eden exposures of the Ohio Valley present some of the best and most complete sections of the Cynthiana formation of Kentucky. The confusion in the nomenclature and correlation of the sub-Eden beds has prevented their complete correlation with the type Cynthiana exposures further south in Kentucky. To establish the background against which the correlation of the sub-Eden beds will be attempted, the Cynthiana formation is here briefly reviewed.

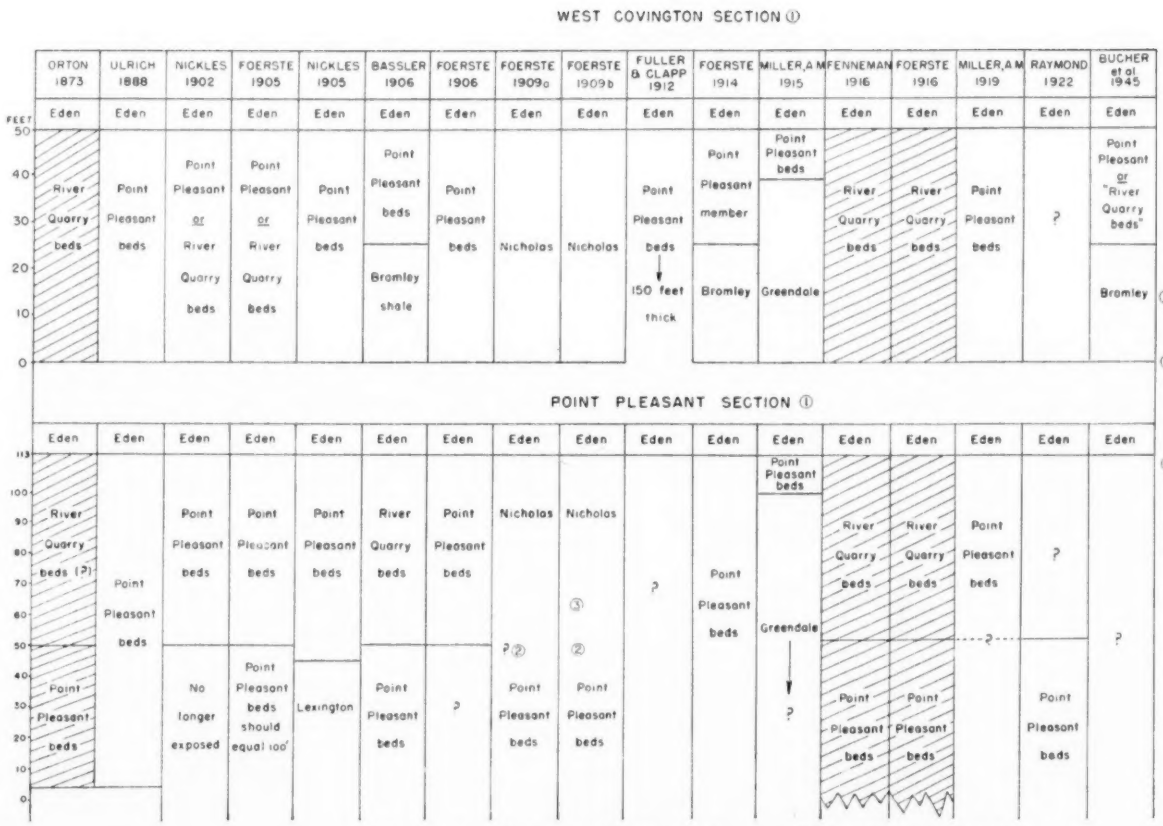

FIG. 2

① All sections measured from low water in 1873 (as closely as possible.)

② Lower limit of Nicholas is lowest appearance of CRYPTOLITHUS tessellatus Green. Position is indeterminate.

③ Greendale may be exposed along the Ohio River at Ivor and Corntown.

Note:- Shaded sections follow Orton's (1873) original definitions.

Fig. 2. Variation in application of the term "Point Pleasant Beds."

Cynthiana formation.—The Cynthiana formation was named by Foerste in 1906. To this formation of limestone and shale he assigned a thickness of 40-90 feet. He believed it to lie unconformably on the Lexington limestones and to be overlain unconformably by the Fulton shales. It is to be noted that Foerste placed the Cynthiana formation in the Cincinnatian series, and not in the Trenton of Kentucky. It crops out around Lexington, Kentucky and as far north as the Ohio River. From its northernmost exposures on the Ohio River, where it is represented by bioclastic limestones and calcareous and non-calcareous shales, the Cynthiana becomes in general more argillaceous southward.

Various subdivisions of the Cynthiana formation have been given in the past by Foerste, A. M. Miller, Ulrich, Bassler, etc. The latest description of these members is given by McFarlan and White (1948).

The presently recognized members of the Cynthiana are as follows:

1. Greendale limestone—named by Foerste (1906) from exposures at the Greendale railroad station north of Lexington, Kentucky. It is a fossiliferous limestone which Foerste believed constituted the lower half of the Cynthiana formation. It is characterized by the presence of *Eridotrypa briareus* (Nicholson), *Eridotrypa aedilis* (Eichwald), *Cyclonema varicosum* Hall, *Orthorhynchula linneyi* (James), *Rafinesquina alternata* (Emmons), *Escharopora falciformis* (Nicholson), *Constellaria emaciata* (Ulrich and Bassler), *Hebertella occidentalis* Hall, *Platystrophia colbiensis* Foerste, etc.

2. Bromley shales—named by Bassler (1906) from exposures in the bank of the Ohio River at Bromley, Kentucky. He assigned a thickness of 30 feet to the Bromley shales.

3. Nicholas limestone—named by Foerste (1909a) from exposures in Nicholas County, Kentucky. It is a quarry rock. Foerste stated that it overlies the Greendale and underlies the Fulton. He held that the sub-Eden beds of the Ohio River banks which carry *Cryptolithus tesselatus* belong to the Nicholas limestone. It is interesting to note that in 1924 Foerste followed Bassler's (1915) division of the Cynthiana into Rogers Gap, Gratz, Bromley and Greendale, thereby abandoning his own term Nicholas.

4. Millersburg limestone—named by Foerste in 1914. He described it as the *Orthorhynchula* phase of the Cynthiana. It is a rubbly, argillaceous, fossiliferous limestone, and bounded below by the zone of *Allonychia flanagenensis* Foerste. It is present on the eastern side of the Cincinnati arch, and Foerste believed it to be an approximate equivalent of the Greendale limestone which is developed on the western flank of the arch.

5. Rogers Gap—named by Foerste in 1914 from Rogers Gap, Kentucky. The name was applied to approximately 25 feet of limestone and shale characterized by *Eridorthis nicklesi* Foerste, *Eridorthis rogersensis* Foerste, *Leptaena gibbosa invenusta* Foerste, etc.

6. Gratz—named by Ulrich in an unpublished manuscript from exposures at Gratz, Kentucky. It is about 50 feet of sparingly fossiliferous shale carrying in the upper part a Rogers Gap fauna (McFarlan and Freeman, 1935).

Beneath the Cynthiana is the Lexington group given by McFarlan and White (1948) as:

Cynthiana

Lexington
- Woodburn
- Brannon
- Benson
- Jessamine
- Logana
- Curdsville

SECTIONS OF THE SUB-EDEN BEDS OF THE OHIO VALLEY

River Quarry section.—This section is compiled from exposures: (1) in the bank of the Ohio River at West Covington, Kentucky, which extend from the Cincinnati Southern Railway bridge over the Ohio River to a point about one mile east; (2) in Banklick Creek south of Latonia, Kentucky; and (3) formerly present at Brent, Kentucky, along the Ohio River. Approximately 50 feet of strata are exposed here.

The River Quarry section is given in table 1. It must be emphasized that in this, and in the two succeeding sections, the fossils listed in each of the zones are not necessarily restricted to that zone. The lists merely show the fauna this writer found in each zone and unless specifically indicated carry no implication concerning the range of these forms. The capital letters used to designate the zones in this table and in tables 2 and 3 do not indicate correlation but are employed merely for easy text reference. (see p. 270 ff.).

This section is the most intensively studied one of the sub-Eden beds of the Ohio Valley and is used as the standard for comparison with all other sections.

The "waved" layers present in zone E (table 1) show symmetrical ripples with broad troughs and narrower but rounded crests. The crests trend parallel to each other. They appear to be oscillation-type ripples. Because of the slight variation of the trend of the ripple marks on different exposures of the same beds and on different beds, the exact value of the strike cannot be determined. All strike measurements, fall, however, between N-S and N 20° W. The lengths from crest to crest are all within the range of 33-44 inches and the wave heights range from 2 inches to approximately 6 inches.

Point Pleasant section.—This section is based upon exposures in a ravine 0.47 miles west of the western end of the Grant Memorial Bridge at Point Pleasant, Ohio, 25 miles southeast of Cincinnati, and in abandoned quarries on either side of this ravine. It includes as far as possible beds extending from low water of the Ohio River in 1873 up to the occurrence of *Triarthrus*

eatoni.[1] The lowest 50 feet of these beds have not been exposed since early in this century, but rock taken from quarries in these beds was used in the construction of the Cincinnati Art Museum and has been examined there.

Exposures at (1) New Richmond, Ohio, (2) Boat Run Creek, 2 miles northwest of Point Pleasant, and (3) abandoned quarries along Highway 52 near Point Pleasant were also examined.

The Point Pleasant section is given in table 2.

The fossils of these beds are almost exclusively in the limestone layers; the shale layers, except for a few local lenses, are barren.

All the men who have worked on the River Quarry and Point Pleasant sections, among whom may be cited S. A. Miller, E. Orton, E. O. Ulrich, J. M. Nickles, A. F. Foerste, and W. M. Linney, have noted that the upper 50 feet of the Point Pleasant section were indistinguishable faunally and lithologically from the River Quarry section. Several, notably S. A. Miller and J. F. James, held that the lower 50 feet of the Point Pleasant section were indistinguishable from the upper 50 feet. However, as Foerste pointed out, *Cryptolithus tesselatus* is confined to the upper part of the Point Pleasant section. It is not present in beds which are believed equivalent to the lower part of the Point Pleasant section, where they are exposed at Carntown. The heavy layer of crinoidal "hash" limestone carrying *Merocrinus*, *Heterocrinus*, and *Escharopora ponderosa* is present in the same position atop both the River Quarry and Point Pleasant sections.

All of the "waved" layers now exposed at Point Pleasant are similar to those at West Covington. The ripples are of the oscillation type, striking N-S to N 25° W, with a length of 36-54 inches and a height of 3-5 inches. It

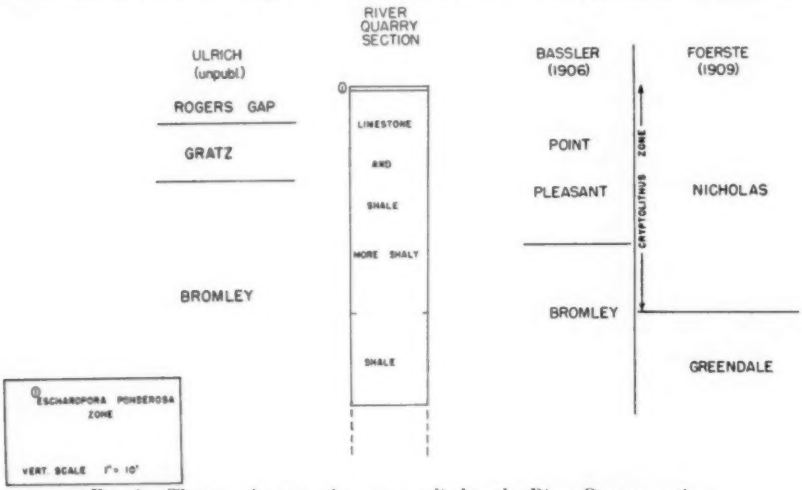

Fig. 3. Three major sets of names applied to the River Quarry section.

[1] Dr. Harry J. Klepser, in a paper presented before the 46th Annual Meeting of the Ohio Academy of Science (1936) entitled "*Triarthrus eatoni* in the Eden of Ohio," demonstrated that the Triarthrus species in the Fulton shale is *Triarthrus eatoni* (Hall) rather than *Triarthrus becki* Green.

does not appear possible to use any single "waved" layer for correlation between the River Quarry and Point Pleasant sections, because they occur at different levels beneath the *Triarthrus eatoni* horizon and vary in trends in different exposures of the same bed.

Ivor-Carntown sections.—The sections at Ivor and Carntown are treated together since they are at the same general topographic elevation and only 1½ miles apart. The exposures at Ivor are located (1) in abandoned quarries which extend from the Chesapeake and Ohio Railroad Station, located approximately 30 miles southeast of Cincinnati and 1½ miles north of Carntown, Pendleton County, Kentucky, southward for a distance of about ½ mile, and (2) in the bed of Goose Creek just behind these quarries. The exposures at Carntown are in the bed and banks of Stepstone and Jiminie Creeks.

Much of the section in Stepstone Creek, especially in the 50 feet from railroad level to the river, is covered. At Ivor, there are no exposures from railroad level to river level. Railroad level at Carntown is at 503 feet, A. T.

Eden shale carrying *Hallopora onealli* (James) occurs 75 feet above the railroad level at Carntown, at the junction of a small tributary with Stepstone Creek. No *Triarthrus eatoni* has been found in this section.

The Ivor-Carntown section is given in table 3.

The approximately 105 feet of beds extending from 20 feet above the river to the base of the Eden (zones B to L inclusive) are part of the Cynthiana formation. The beds underlying them, down to river level, are considered equivalent to the Jessamine (Lexington group) because of the association of *Prasopora simulatrix*, *Prasopora falesi*, *Dalmanella bassleri*, and *Sowerbyella rugosa*. Foerste, noting the occurrence here also of *Strophomena vicina*, believed the beds at river level at Carntown to be equivalent to the Benson, which overlies the Jessamine. The absence of *Rhynchotrema increbescens* (Hall) and *Hebertella frankfortensis* Foerste (Foerste, 1914), however, makes it appear that the beds are equivalent to the Jessamine and not to the Benson.

The contact between the Cynthiana and Jessamine is concealed in the lower 15 feet of zone L, but all workers in this area (except Foerste as noted above) believed the Cynthiana to rest directly on the Jessamine, although no sections have appeared in the literature showing this. The upper 50-60 feet of beds in this section (extending upward from the top of zone K) appear to be the equivalent of the beds exposed in the River Quarry section. The two-foot-thick limestone layer present midway up the face of the quarries at Point Pleasant occurs in a similar position in Stepstone Creek.

In the Ivor quarries, zones F, G, H, and I are well exposed. They are over one-half limestone. However, about ½ mile south of the railroad station at Ivor, there is an embayment in the quarries showing a section equivalent to zones H, I, and J which consists of two-thirds dark blue shale and mudstone and one-third limestone lenses. No *Cryptolithus* is present here, but species of *Lophospira* and *Lingula* occur. These 20 feet of shale and mudstone occur in about the same relative positions as the Bromley shales at West Covington. However, because this shale section changes to a limestone and shale section within a distance of 100 feet, there seems to be no point in calling it Bromley.

The "gnarly" beds of zones K and L were believed by Foerste to be equivalent to Orton's Point Pleasant beds. They are in the same position, approximately 50 feet below the Eden, and Orton had noted the "nodular" appearance of some of the limestones of the original Point Pleasant beds.

The ripples in the "waved" layer in zone D strike N-S and have a wave length of about 40 inches, and an amplitude of about 4½ inches, thereby agreeing in trend, wave length and amplitude with the ripples in all the "waved" layers noted in the Point Pleasant and River Quarry sections. However, the "waved" layer in zone I, although it has ripples of the oscillation type, with a length of 46 inches, differs from all other "waved" layers found, in that the ripples trend E-W.

Minor sections.—Other less extensive sections of the sub-Eden beds of the Ohio River banks are exposed in 9 Mile Creek, 12 Mile Creek, and upstream from Carntown as far as Higginsport. The sections upstream from Carntown are not extensive and no detailed field work was done there.

The exposures at 9 and 12 Mile Creeks are discussed here.

The 12 Mile Creek section was discussed by McFarlan and Freeman (1935) on the basis of work done by W. H. Shideler. The beds underlying the Fulton are given (p. 1979) as:

"(e) 4½ ft. *Dalmanella emacerata* jumble; top of Rogers Gap.
(d) 3½-4½ ft. Massive crinoidal limestone with *Merocrinus curtus.*
(c) 2-3½ ft. Massive limestone. Crinoid jumble with *Merocrinus curtus.*
(b) 2 ft. 1- to 2-inch ledge on top of massive limestone. *Plectambonites* (*Sowerbyella*) *rugosa* (c); *Merocrinus curtus.*
(a) 0 ft. Creek level."

The overlying Fulton carries *Hallopora onealli. Eridorthis nicklesi* is present both in the Fulton and in the Rogers Gap. *Eridotrypa aedilis* is apparently restricted to the Rogers Gap.

The ledge in (b) carrying abundant *Sowerbyella rugosa* is present in the Point Pleasant section, as is the overlying *Merocrinus* "hash" layer. The zone of abundant *Sowerbyella rugosa* cannot be found in the River Quarry section underlying the Fulton. *Eridorthis* has not been found in the beds underlying the Fulton either at West Covington or at Point Pleasant.

At 9 Mile Creek the contact between the beds carrying *Hallopora onealli* and *Eridorthis nicklesi* and the underlying beds is covered for an interval of about 10 feet. The "Cynthiana" exposures are poor and fragmentary, but enough is shown to indicate that they are about half limestone and half shale, with very irregular "waved" layers. *Cryptolithus tesselatus* and *Isotelus* fragments are common. All the measured oscillation ripples of the "waved" layers trend approximately NNE-SSW. The trend of these oscillation ripples is similar to that shown at West Covington and Point Pleasant in the same formation.

Foerste (1914) stated that *Eridorthis* was found in 9 Mile Creek "at a similar horizon" to its occurrence at Brent, Kentucky. *Eridorthis* at Brent occurred "distinctly below" the layers carrying *Cryptolithus*. Since *Cryptolithus* is found in the lowest beds now exposed in 9 Mile Creek, it is impossible to confirm Foerste's statement, or to determine the exact horizon at which he found *Eridorthis*.

SUMMARY OF PRESENT FIELD WORK

1. The zone of *Escharopora ponderosa* with a thickness of about 2 feet appears to be a consistent horizon at or near the top of the exposures of the sub-Eden beds of the Ohio Valley.

2. *Cryptolithus tesselatus* is present in all exposures in the valley and is limited to the approximately 35 feet of strata immediately underlying the *Escharopora ponderosa* zone. It is suggested that the lowest occurrence of *Cryptolithus tesselatus* marks the base of the Nicholas member. For reasons to be given later, however, the top of the Nicholas formation should not be taken as the zone of *Escharopora ponderosa* but rather the first appearance of *Eridorthis nicklesi*.

3. Beds below the *Cryptolithus tesselatus* zone in all the exposures carry a typical Greendale fauna and it is suggested that the name Greendale be applied to these beds.

4. The Bromley shale appears to be a local facies which crosses the major faunal zone boundary and may well be discarded as a formational name (see discussion of Bassler's nomenclature below).

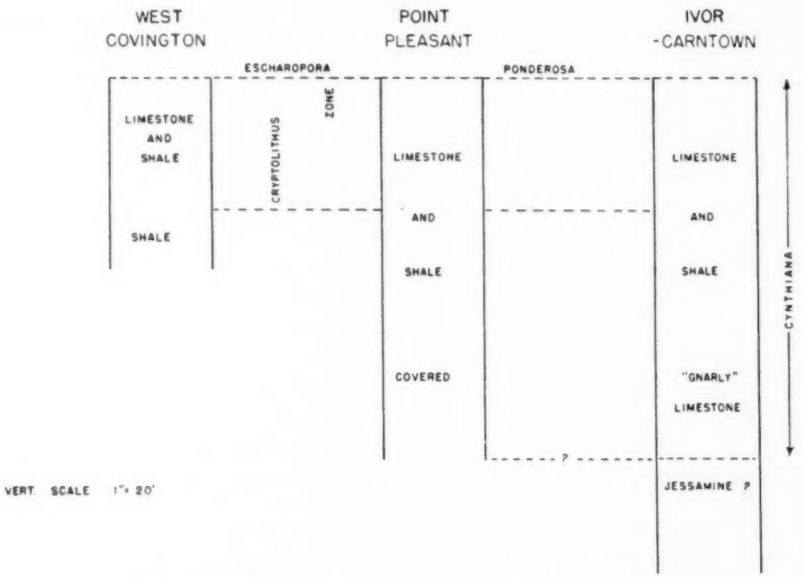

Fig. 4. Summary of the sub-Eden exposures in the Ohio Valley.

DISCUSSION OF THE NOMENCLATURE OF THE SUB-EDEN BEDS OF THE OHIO VALLEY IN THE LIGHT OF THE PRESENT INVESTIGATION

The essential information contained in the three sections given above in detail is shown schematically on figure 4.

Orton's nomenclature.—Although Orton's names have priority, they are based exclusively upon the level of the Ohio River at West Covington, Kentucky in 1873. No faunal or lithologic distinctions are given as the basis of his names. Construction of navigation dams on the Ohio River has changed the level of the river considerably since Orton's time. For these reasons it is thought best to abandon Orton's nomenclature. The subsequent misuse of Orton's names obviously need not be considered for use today.

Bassler's nomenclature.—The first new name applied to these beds was the term Bromley used by Bassler (1906) for the lower 25 feet of the River Quarry section as best exposed at Bromley, Kentucky. The separation of the Bromley beds from the overlying remainder of the Point Pleasant section is apparently done purely on the basis of lithology. The lower 25 feet of the River Quarry section is predominantly shale. The type exposures at Bromley, Kentucky were destroyed by an ice jam on the Ohio River about 1917. There are several reasons why the term Bromley is almost impossible to use today:

1. There is no sharp top to the shaly lower part of the River Quarry section. The change from limestone and shale of the upper part to predominantly shale of the lower part is very gradual.

2. The Bromley is not a consistent lithologic unit; it appears to be a fairly localized shaly facies. It is not found in any of the other exposures along the Ohio River.

3. As shown in figure 4, the most important faunal marker in this area is the zone of *Cryptolithus*. The top of the Bromley as designated by Bassler does not coincide with the bottom of the *Cryptolithus* zone at West Covington. It is therefore impossible to distinguish the Bromley shales from the beds immediately above them.

Ulrich's nomenclature.—The nomenclature applied to these beds by Ulrich was never published and will not be considered here.

Foerste's nomenclature.—The names applied to these beds by Foerste (1909a, b) are derived from the type exposures of the Cynthiana in Kentucky. This was the first time that the fossils were used as the basis of stratigraphic nomenclature here. Since the present detailed investigation confirms Foerste's delineation, it is suggested that his nomenclature be used.

THE BASE OF THE CINCINNATIAN SERIES

The top member of the Cynthiana is the Rogers Gap. This member is distinguished from the Nicholas limestone below it by the presence of *Eridorthis nicklesi* and *Eridorthis rogersensis*. These two species also occur in the immediately overlying Fulton shales (base of the Cincinnatian). Therefore the Rogers Gap and Fulton together may be said to constitute the *Eridorthis* zone. Despite detailed review of the literature, no method was found for faunally separating the Fulton and Rogers Gap, nor has the present investigation revealed any such distinction. The Rogers Gap is usually spoken of as

a limestone and the Fulton as a shale. Nevertheless at Gratz, Kentucky the Rogers Gap is shale; the River Quarry section shows no limestone *Eridorthis*-bearing beds, the first appearance of this form being in the Fulton shales; at Point Pleasant no *Eridorthis* was found, although of course some may be present; at Carntown again no *Eridorthis* was found below the Eden shales (Fulton); a summary of the occurrence of *Eridorthis* in 9 Mile and 12 Mile Creeks has been given above.

Several years ago Bucher (1919) advanced a hypothesis for the deposition of the limestones and shales of this area to which this writer subscribes. Briefly, this is:

1. Deposition of mud, containing fossils.

2. Reworking of this mud by occasional large waves. The mud and some of the fossils are thrown into suspension. The fossils being heavier, settle first and form what are later to be bioclastic limestone layers. The mud, now barren of fossils, then settles and is later compacted to form the shale.

Therefore, where the seas were shallow and storm waves more frequently disturbed the bottom, the section exposed today should be predominantly limestone, and where the seas were deeper, shale.

Current detailed study at the University of Cincinnati has tended to confirm Bucher's hypothesis.[2] If the hypothesis is correct, it offers a very acceptable explanation of the Rogers Gap-Fulton deposition.

The Fulton has been shown to have been deposited in a sea extending over this area (kratonward) from the northeast. It thickens considerably northeastward (Fenneman, 1916). When that sea invaded here (fig. 5), there would have been shallow water landward and deeper water seaward. As the advance continued, areas of former shallow water would have become deep water as in b (fig. 5). From all of this several inferences may be drawn and then tested by the facts:

a) Where the seas were lapping against the land (southward), the water was shallow and the final sedimentary facies there would be predominantly bioclastic limestone.

b) As the land to the south subsided further, the sea would encroach further and the areas that had formerly been shallow would become deeper.

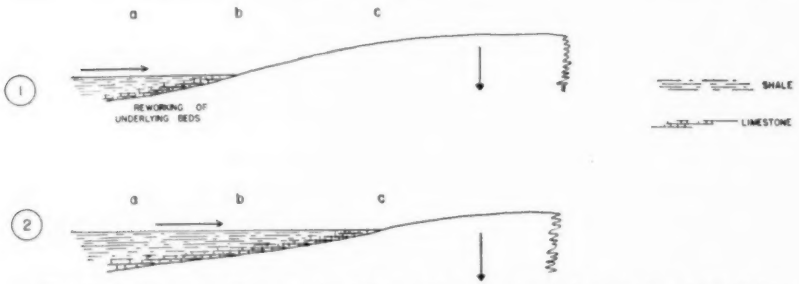

Fig. 5. Diagram to illustrate deposition of limestone and shale facies of the Fulton as suggested in this paper.

[2] Richard H. Bruns, University of Cincinnati, oral communication.

The deposition would then be predominantly shale, the more limey phase being still further south (fig. 5).

c) The two facies of the Fulton invasion, both limestone and shale, should carry essentially the same fauna, which would be definitely distinguishable from that of the underlying Cynthiana beds.

d) The topmost limestones of the underlying beds would show wave-reworking.

e) The Fulton invasion should transgress onto older beds toward the south.

The typical Fulton is characteristically dominantly a shale. Where, then, is its predominantly limestone phase? It now appears quite logical that this phase is the Rogers Gap, which fits in with the above deductions. Northward, away from the center of the Jessamine dome of central Kentucky (deeper water), the Rogers Gap limestone phase cannot be found along the Ohio River. The Fulton and Rogers Gap together constitute the zone of *Eridorthis nicklesi*. This zone is distinguishable faunally from the underlying beds. The Rogers Gap cannot be distinguished faunally from the Fulton at the present time, to the writer's knowledge. The Rogers Gap and Fulton rest northwardly on the Nicholas, and southwardly on the Greendale. They are not now present over the top of the Jessamine dome to the south, although of course they could have been deposited here and later eroded off. The Fulton (shale phase) is absent in some places toward the center of the Jessamine dome, and the Million (Eden) rests directly on the Rogers Gap limestone. The uppermost beds of the limestone underlying the zone of *Triarthrus eatoni* (the Fulton shale) at West Covington show wave-reworking (Fenneman, 1916).

If the above hypothesis be correct, the Rogers Gap must be looked upon as a limestone, shallow water facies of the Fulton. In this event it is difficult to see how the boundary between the middle and upper Ordovician in this area can be drawn *between* them—a point which appears to support those workers, notably Foerste and A. M. Miller, who have presented evidence in favor of including the Cynthiana formation in the Cincinnatian rather than the Trenton series.

In brief, the evidence favoring the extension of the Cincinnatian series downward to include the Cynthiana formation is:

1. The Cynthiana formation carries few species in common with the typical Trenton of New York.

2. Many New York Trenton forms occur below the Cynthiana in Kentucky.

3. If the Rogers Gap is taken as the top of the Cynthiana and the Fulton as the base of the Cincinnatian series, then it is immediately apparent from a casual examination of faunal lists that the faunal break at the base of the Cynthiana is greater than the faunal break between the Cynthiana and the overlying series, and greater than that between the Nicholas and Rogers Gap. The use of the Fulton-Rogers Gap "contact" as the plane dividing the middle and upper Ordovician is further weakened if these are merely different facies of the same formation as postulated above.

4. Until recently a pronounced unconformity was believed to exist at the base of the Cynthiana. It should be pointed out that McFarlan and White (1948), on the basis of a reclassification of the Perryville, believed this unconformity to be illusory. They called the Cynthiana "an invasion of a region of low relief". But the fact that the Cynthiana rests on the Benson at Carntown and on the Woodburn further south in Kentucky is unexplainable except as an unconformity.

5. The Fulton has been shown to be an invasion from New York and Canada. It thickens distinctly to the northeast (Fenneman, 1916). It is conceivable that the arrival of the Fulton (Utica) sea in the area of Cincinnati was distinctly later than the deposition of the main mass at least, or possibly the whole of the Utica shales in New York.

6. The Fairmount beds of the Maysville group (Middle Cincinnatian) carry a recurrent Cynthiana fauna (not "recurrent Trenton" as often cited).

7. As regards the lithologic break between the middle and upper Ordovician in the Ohio River exposures, (the Cynthiana is predominantly limestone and the Eden is shale), the Cynthiana formation becomes distinctly more shaly southward in Kentucky, and has here a topographic expression indistinguishable from the Eden.

TABLE 1

River Quarry Section

(Modified after E. O. Ulrich, unpublished)

Zone	Beds	Remarks	Fossils
A	6-9 feet of yellow and yellow-blue shale	Top is approximately 60 feet above present low water. The fossils are restricted to a few thin limestone layers in the upper 2-5 feet.	Crepipora venusta Ulrich Arthropora kentuckiensis (James) Ceocloclema commune (Ulrich) Sticktoporella flexuosa (James)
B	6 in.-2 feet coarse-grained crinoidal limestone	This layer contains clayey and granular limestone pebbles that appear to be derived from underlying beds and do not show abrasion. It is the top of Orton's River Quarry beds.	Heterocrinus and Merocrinus hash Escharopora ponderosa (Ulrich)* Prasopora sp.
C	3-5 feet blue finely crystalline limestone	Some drab shale partings up to 4 inches in thickness.	Dendrocrinus dyeri (Meek)* Lingulops norwoodi (James)
D	2-3 feet drab shale and shaly limestone		ostracods
E	6 in.-1 foot coarse-grained limestone	This is the first "waved" layer of limestone showing what appear to be ripples of the oscillation type.	Fossil hash Eridotrypa aedilis (Eichwald) Orthorhynchula linneyi (James) ?
F	4 feet of shale with interbedded thin layers of fossiliferous limestone		Eridotrypa briareus (Nicholson) c Aspidopora calycula (James) c Ectenocrinus simplex (Hall) ? Cryptolithus tesselatus Green
G	1 foot coarse-grained fossil hash limestone	A "waved" layer. This zone is not exposed at present time.	Dalmanella bassleri Foerste crinoid and bryozoan hash
H	5 feet of alternating blue limestone and shale	The limestone layers are composed of a fossil hash. The layers of limestone and shale are about 5 or 6 inches thick. Not well exposed at present time.	Cryptolithus tesselatus Green c

I	3 feet of blue limestone	Separable into several layers. It is composed of a fossil hash. A thin bed of yellow shale occurs at base.	Zygospira recurvirostris (Hall) Lingulops norwoodi (James) Prasopora cf. simulatrix Ulrich Dalmanella cf. bassleri Foerste Rafinesquina alternata (Emmons) Eridotrypa briareus (Nicholson)
J	11-15 feet of blue limestone and drab blue shales	Alternation of limestone and shales becoming more shaly as section is descended. Lower 4 feet are about two-thirds shale.	Ctenodonta cf. alta (Hall) Whiteavesia cincinnatiensis (Hall and Whitfield) Sinuites cancellatus (Hall) Cyrtolites retrorsus Ulrich and Scofield Lophospira abnormis Ulrich Cryptolithus tesselatus Green Eridorthis sp. (at Brent, Foerste, 1914)
K	15 feet of drab and blue calcareous shales	These beds extend down to present river level but only the upper 5 feet are now exposed. Some occasional thin fossiliferous limestone layers are present. (River level approx. 442 feet)	ostracods "Gerasaphes ulrichana" Clarke* Cryptolithus tesselatus Green** Isotelus benjamini Ulrich Lingula whitfieldi Ulrich*
L		Layers formerly exposed here down to a lower river level.	Leptobolus lepus Hall Escharopora ponderosa (Ulrich) ? Lingula sp. Lingulops norwoodi (James) Arthropora kentuckiensis (James)

** *Cryptolithus tesselatus* occurs in the limestone layers in the upper 2 or 3 feet. It cannot be found in beds below this level where they are exposed in Bankslick Creek.

* = apparently restricted to this zone. c = very common.

Additional more common fossils reported from these beds (exclusive of zone A) are: *Tetradium fibratum* Sagord, *Lingula covingtonensis* Hall and Whitfield (restricted to upper 25 feet), *Lyrodesma subplanum* Ulrich, *Byssonychia byrnesi* Ulrich, *Whiteavesia pulchella* (Ulrich), *Cyclonema varicosum* Hall, *Cyclora* sp., *Ceratopsis intermedia* Ulrich, *Modiolopsis oblonga* Ulrich, *Isotelus* frag. (c).

A very complete list of River Quarry section species is given by Nickles (1902).

TABLE 2

The Point Pleasant Section

Zone	Beds	Remarks	Fossils
A	Fulton	Clay shale about 5 feet thick, whose bottom is at an elevation of 560 feet. Foerste (1905) said it was 113 feet above river level at that time.	Triarthrus eatoni Hall
B	18-inch coarse-grained crinoidal limestone layer	Contains clayey and limestone pebbles.	Escharopora ponderosa (Ulrich)* Heterocrinus and Merocrinus hash
C	9-10 feet limestone and shale	This section is about two-thirds limestone. No limestone layer exceeds 8 inches in thickness.	Sowerbyella rugosa (Meek)—common in thin ledge near top. Eridotrypa aedilis (Eichwald) Rafinesquina sp. Cryptolithus tesselatus Green c
D	Approx. 20 feet limestone and shales	The limestone to shale ratio is about 3 to 5. A "waved" layer of limestone occurs at the bottom.	Cryptolithus tesselatus Green Cyrtolites retrorsus Ulrich & Scofield (in shaly lens) Zygospira recurvirostris (Hall)
E	2-foot limestone layer	Exposed about halfway up face of the quarries.	Eridotrypa aedilis (Eichwald) Rafinesquina alternata (Emmons) Heterotrypa ?
F	3 feet of limestone and shale	Exposed now but covered in 1891.	Cryptolithus tesselatus Green c not found below this zone

G	Approx. 23 feet of limestone and shale	This section has a slightly higher proportion of shale to limestone than zone D.	Isotelus frag. Rafinesquina cf. alternata (Emmons) Lingulops norwoodi (James)
	———— Level of Highway 52 and floor of quarries ————		Found loose on floor of quarries: Sinuites cancellatus Hall Whiteavesia sp. Eridotrypa aedilis (Eichwald)
H		No longer exposed. James (1891) said that 20 feet of rocks are covered in the ravine ½ mile west of Point Pleasant, but other exposures in ravines nearby show "an extensive bed of shale . . . apparently destitute of organic remains."	
I		No longer exposed. 34 feet of limestone and shale in about equal proportions (James, 1891, p. 102). Down to river level. There are a few layers of yellow shale present. "Waved" layers of limestone occur. Orton (1873) noted that the limestones often have a "nodular" texture.	Listed by James (1891): Orthis sp. Asaphus Isotelus ? sp. Calymene sp. Strophomena Rafinesquina ? sp. Sowerbyella sp. Escharopora falciformis (Nicholson)? Dalmanella cf. meeki (Miller)

* = apparently restricted to this zone. c = very common.

The Cincinnati Art Museum was built of rock quarried from zones H and I. These rocks, from which it was not possible to remove specimens, contain: *Cyclonema varicosum* Hall, *Isotelus* frag., *Lophospira* cf. *abnormis* Ulrich; no fragments of *Cryptolithus* are present.

Foerste believed that *Hallopora multitabulata* (Ulrich) and *Prasopora simulatrix* Ulrich may formerly have occurred at river level because of their occurrence at a similar position at Ivor and Carntown.

TABLE 3

The Ivor-Carntown Section

Zone	Beds	Remarks	Fossils
A	1-foot crinoidal hash limestone layer	This layer immediately underlies 5 feet of shale carrying *Hallopora onealli* (James).	Escharopora ponderosa (Ulrich)* Merocrinus hash
B	2½ feet coarse-grained limestone	Granular limestone layer with some crinoid stem fragments.	Schuchertella higginsportensis (Foerste) ?
C	11 feet of limestone and shale	The shaly parts of this section (constituting about 2/5 of the section) are covered in part. The limestone layers are dense and up to 2 inches in thickness.	Cryptolithus tesselatus Green Rafinesquina cf. alternata (Emmons) Zygospira recurvirostris (Hall) Eridotrypa briareus (Nicholson) Isotelus frag.
D	8 feet of limestone and shale	Granular fossiliferous limestone. A "waved" layer occurs near middle of zone. The shale occurs in narrow (1 inch) partings and one 1 foot layer.	Eridotrypa aedilis (Eichwald) Cryptolithus tesselatus Green Lingulops cf. norwoodi (James) bryozoa
E	6 feet covered		
F	10 feet limestone and shale	About one-half limestone and one-half shale occurring in layers approximately 1 foot thick. Shale is drab gray. A layer of crinoidal limestone about 2 feet thick occurs at base.	Eridotrypa aedilis (Eichwald) Cryptolithus tesselatus Green (lowest occurrence) Modiolopsis cf. oblonga Ulrich Cyrtolites retrorsus Ulrich & Scofield Isotelus frag.
G	3 foot 3 inches of limestone	Lower half is 18 inches crinoidal hash. Upper half is 19 inches crinoidal "waved" layer.	Isotelus frag.

H	9 feet of limestone and shale	Limestone is fossiliferous hash in part. Many bryozoan fragments. Shale is yellow-brown and blue.	Whiteavesia sp. Rafinesquina cf. alternata (Emmons) Byssonychia byrnesi Ulrich
I	1 foot granular limestone	"Waved" layer.	hash
J	15 feet limestone and shale	This zone is poor in fossil remains. It is predominantly limestone and has been quarried just south of the railroad bridge at Carntown.	Isotelus benjamini Ulrich Lophospira abnormis Ulrich Eridotrypa sp. Dalmanella bassleri Foerste
K	10 feet of "gnarly" limestone	This zone extends down to railroad level.	Orthorhynchula linneyi (James)
L	30 feet of limestone and shale	From the top of zone K down a distinct change in lithology occurs. The limestone has a "gnarly" structure. The calcereous shale shows a similar appearance in a less pronounced fashion. The section is made up of equal parts of limestone and shale, no layer exceeding 1 foot in thickness. The lower 15 feet of zone L are not clearly exposed.	Cyclonema varicosum Hall Rafinesquina cf. winchesterensis Foerste Constellaria emaciata (Ulrich and Bassler) Batostoma sp. Escharopora falciformis (Nicholson)
M	20 feet to river level	Not exposed.	Foerste (1914) lists at river level: Dalmanella bassleri Foerste c Hallopora multitabulata (Ulrich) c and at 20 feet above river level: Prasopora cf. simulatrix Ulrich Prasopora cf. falesi (James) Eridotrypa aedilis (Eichwald) Eridotrypa trentonensis (Nicholson) Platystrophia colbiensis Foerste Zygospira recurvirostris (Hall) Sowerbyella rugosa (Meek)

* = apparently limited to this horizon. c = very common.

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IMPACTITE[1] SLAG AT BARRINGER CRATER

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ABSTRACT. Impactite has been found at the Arizona meteorite crater; it differs from the impactite described by L. J. Spencer in connection with the meteorite craters at Henbury, Australia, and at Wabar, Arabia, which was silica glass. The Arizona material is composed of dolomite, silica, and calcium carbonate. Like the silica glass of Spencer it contains particles of metallic nickel-iron but less abundantly. The ratio of iron to nickel and cobalt has been determined by F. G. Hawley. Quantitative measurements were made in one excavation, and the yield of impactite found to be from 54 to 162 pounds per cubic yard. Its tardy discovery is explained as due to confusion of the impactite with volcanic cinders in the area.

Nickeliferous silica glass such as that described by Spencer in 1933b has never been reported from the Barringer Meteorite Crater. Non-nickeliferous quartz pumice known as lechatelierite has been found in small quantity in the depths of the crater pit and has been described in some detail by Barringer (1909), Merrill (1908), Rogers (1930), and others.

In 1950, the present writer exhibited a few slivers of a nickeliferous, transparent, slightly yellowish glass that had been collected magnetically on the outer slope of the northern rim two years before. However, subsequent searches have failed to reveal any additional material of this kind whatever. As was noted at the time, this sample did not conform exactly to the description of impactite given by Spencer (1933b), but more nearly resembled the Libyan Desert glass.

In view of the many other evidences of heat in connection with this great impact, many astronomers, geologists, and meteoriticists have expressed surprise at the absence of fusion in any but the white Coconino sandstone. It is understandable that silica glass would not be formed in a pure limestone, but in an arenaceous lime such as the Kaibab formation and in the Moenkopi sandstone one would expect some products of fusion, especially now that such abundant evidence of the vaporization of iron and nickel indicates a temperature of 3200°C. or above, and the melting point of silica is only 1710°C.

DISCOVERY[2]

In 1949, an intensive and rather widespread search was made for metallic spheroids accompanied by critical observations on each sample of soil taken. During these operations certain minute, light-colored, magnetic particles of various shapes were found which, though differing markedly from the metallic spheroids, gave a positive nickel test.

The writer was inclined to regard these as small bits of lechatelierite in which spherules of metal had been captured, but has never been able to find a sample of typical lechatelierite from the crater pit that contained any nickeliferous inclusions.

[1] The word *impactite* was suggested by H. B. Stenzel and used by Virgil Barnes in 1940 (p. 558). It is adopted for use here because it now becomes evident that forms other than silica glass are produced by impact, their character differing in accordance with the formations invaded.

[2] The survey which resulted in the discovery of the impactite here described was in part financed by Mr. Alfred Knight of Phoenix, Arizona, a business man and an amateur astronomer.

We now recognize that we were dealing here with small impactite bombs containing minute particles of nickel-iron. Recently we have examined polished sections of many such.

From 1949 to 1952 these studies were almost entirely confined to the upper four inches of soil, but late in 1952, when the Arizona State Highway Department excavated for gravel in the lower part of the northwest rim, an opportunity was presented to investigate a considerable sample of that part of the rim rubble which had been protected from surface disturbances since its deposition.

Here, protected from frost and the wear and tear of wind, rain, and other sources of attrition, were found the little bits of frothy glass in their original forms. Thousands of minute, gray, porous bombs, many of which were so frail that they could be crushed readily between finger and thumb, were mingled with larger specimens, some of which were as large as filberts. The breaking of a small corner of one revealed an extreme porosity, also a frailness which had not been encountered in any of the volcanic cinders that are such a familiar feature of the plain adjacent to the crater. A magnet induced a very weak reaction in the specimen, but this was not convincing since many of the volcanic cinders show the same reaction.

The volcanic ash of this area is considered to be more recent than the formation of the crater. According to Tilghman (1906), Fairchild (1907), Jakosky, Wilson and Daly (1932), and others, the lake deposits in the pit contain a thin layer of ash which seems to correspond to the ash deposit on the plains. On the basis of archeological and tree-ring studies it seems to have been very well established that slightly less than 900 years ago there was a showering of ash from Sunset Crater, 40 miles to the northwest, which may have encompassed this area. This may well have been the source of the ash deposit in the lake beds and on the surrounding plains. On the other hand, a sample of the rim rubble taken at a depth of 4½ feet below the present surface of the rim showed abundant meteoritic spheroids and also numerous specimens of the little glassy bombs, but no ash. This would seem to indicate that there had not been a blanketing of the area with volcanic ash previous to the crater's formation. At the same time it proved that the newly found form had either preceded or accompanied the crater's formation. The new-found objects were treated in several ways:

First, one was ground and polished, revealing an extremely vesicular and spongy-looking interior, strongly rust-stained, with numerous bright metallic particles.

Next, the mass was crushed in a mortar and tested for nickel. It gave a strong positive reaction with dimethylglyoxime.

When one of the specimens was crushed and the magnetic particles removed and examined under a microscope, they were found to be much like the little metallic spheroids which had become so familiar and speculation arose as to whether the surface spheroids (Nininger, 1951) which had been collected during the last few years had been released from similar glassy bombs that had been ground up by surface attrition.

DESCRIPTION

While evidently produced by a similar force, the impactite at Barringer Crater differs in several details from the silica glass found at Wabar and Henbury craters as described by Spencer (1933b).

Fig. 1. Impactite bombs gathered on the rim of Barringer Crater. These bombs, when sectioned and polished, show particles of nickel-iron.

The second from the top on the right has had its original surface removed by erosion. The second from the left on the bottom shows two small attached bomblets, one almost completely imbedded. (Photograph from the Smithsonian Institution.) Magnification about 0.7X.

In the first place, although its vesicular character and often ropy appearance strongly suggest that it was produced as glass, X-ray studies in the laboratories of the Mellon Institute reveal that it is to a large extent crystallized. In the second place, its composition has been shown to be about as much dolomite as silica, and in some cases mostly dolomite. In the third place, the highly glazed black glass of Spencer is almost entirely absent at the Arizona Crater where the exteriors of the bombs are nearly all free of gloss, having a dull appearance and being usually of a gray color with many specimens varying to greenish, reddish-brown, yellowish and rarely almost white at the surface. Their interiors range from black (rare) through various shades of gray, brown, green, yellow, and amber, rarely bluish or pure white. The interiors of the vesicles are often somewhat lustrous, sometimes highly so, in contrast with the dull exteriors of the bombs.

All the bombs are characterized by an outer zone which is much more compact than the main body, and the Mellon Institute found this outer zone to be more crystalline than the interior of specimens examined. The Institute also reported that augite was a prominent mineral indentified in the interior of a bomb examined.

The forms of the Arizona bombs seem to compare very well with those described from Henbury and Wabar craters except that the pimply surface is not as prevalent as Spencer describes (1933b), although it is definitely present. Another feature, however, which seems to be closely related has been noted repeatedly in the Arizona bombs and that is the presence of subsidiary bomblets attached to large bombs (fig. 1, second from lower left). These are usually spherical and evidently had solidified before colliding with the larger mass while it was still plastic. In some instances these are more than half embedded in the latter. Others are barely attached.

Of the smaller bombs some are spherical. This form is most frequent in the microscopic size range. Quite a few of the smaller spheres show a cup-like pit on one side. Pear-shaped bombs are common, especially among the smaller sizes, as are cylinders with rounded ends, dumbbells, crescents, and claw-like specimens, but the great majority are irregular and nondescript.

A few of the rounded forms have, on being broken, shown small white spheres in their centers, and many show included rock fragments. Some of these look as if rock fragments had collided with blobs of molten glass which partially or wholly enfolded them (fig. 2). Some of the included fragments appear to be white Coconino sandstone, others the Moenkopi formation which overlies the Kaibab formation, while still others seem to be of the Kaibab formation.

Quite a number of rock fragments have been found showing a partial fusion on their surfaces. Some are fully fused on one side, others lightly fused all over, still others have a thick layer of slag plastered on one side as if a blob of molten material had fallen on them. The slag in such cases shows rounded edges as if a thick viscid mass had partially flattened itself before solidifying.

Fig. 2. Rock fragments enfolded by impactite. Magnified about 2.5X. (Photograph from the Smithsonian Institution.)

Fig. 3. Specimens of figure 2 viewed from opposite side. (Photograph from the Smithsonian Institution.) Magnification about 2.25X.

Nearly all the bombs when excavated show a layer of fine sand adhering to one side. This sand seems to have enough lime in it to bind the grains together and to the bomb's surface. Dilute acid dissolves the cementing agent so that the deposit may be rubbed off by the fingers.

All the bombs tested in our laboratory by grinding were found to contain at least some small metallic particles. In some of them these particles were fairly abundant, running into hundreds. Others contained very few, so that half or more of the specimens had to be ground away before any were revealed. E. P. Henderson reported that a few of those submitted to the U. S. National Museum failed to reveal any metallics.

The metallic inclusions were far less abundant than those found by Spencer in his silica glass nor were they always spherical as described by him and as shown in his published photographs (1933b). Ours are sometimes spherical but are often irregular in form.

An analysis made of these inclusions by F. G. Hawley showed that the nickel:iron ratio is approximately midway between that of the nickel-iron meteorites (1:13) and that found in the metallic spheroids (1:4.4). The metallic particles removed from the impactite showed a nickel:iron ratio of 1:7.4.

OCCURRENCE

The results of these tests indicate that these scoriaceous masses do not have a terrestrial origin. Hence they must be related to the impact of a meteorite. Directly across the crater from where these bombs were excavated there are considerable numbers of clinker-like masses on the surface of the crater rim slope, now recognized to be similar impactite. Others have incorrectly called these volcanic cinders. That is a natural assumption because volcanic materials are scattered over this part of Arizona, and actually the nearest outcrops of volcanic rocks occur on the same side of the crater as these clinker-like masses.

However, the incorrectness of this interpretation could very well have been detected had earlier investigators searched the area between the meteorite crater and the lava outcrops to the south and southwest. When we traversed this zone looking for impact bombs we found none after reaching a distance of 1½ miles from the crater rim nor did we find any volcanic particles that could be confused with them. Volcanic ash was more abundant as we approached the lava beds from any direction, but this ash never occurred in forms to be confused with the impactite.

Specimens of volcanics were brought from the cinder mountains to the west and from the lava deposits to the south and were subjected to the same laboratory tests as had been applied to the impactite. No specimen showed the least trace of included metal particles nor any trace of nickel when tested chemically.

Since the area around the crater was known to be rich in nickel-iron spheroids, it seemed wise to determine whether the presence of nickel might be due to the lodgement of minute spheroids in the vesicles of the porous bombs. Inspection of polished sections revealed that the metallic inclusions

were not in the pores but actually embedded in the slag of the reticulum, indicating that they must have been enveloped by the liquid during the process of bomb formation.

The impactite appears to be unequally distributed on the rim. Although it has now been found on all sides of the crater, it has been found in abundance on the surface in only one sector of the rim, viz., the southeastern sector. However, it is found equally abundant in the excavation in the northwest sector. This excavation reached to the undisturbed Moenkopi formation, which is the original surface formation of the region, and the heavy deposit of bombs was found in the rubble 2 to 4 feet above this formation. The identifiable fragments which compose the rubble consist of three formations in approximately the following percentages: Moenkopi, 25 percent; Kaibab, 55 percent; and Coconino, 15 percent. Most of the latter is unconsolidated sand, some of which is bound to the bombs and rock fragments by calcareous cement. Samples of rubble taken from this horizon yielded from 54 to 162 pounds of impactite per cubic yard.

It is probable that the rich surface accumulation of bombs on the southeast rim is also in the same horizon of the rubble, although no excavation has been made to prove it. It is noted, however, that no bombs have been found in the mounds of boulders and coarser rubble but only in those areas where erosion has removed nearly all the ejectamenta. It is probable that if the mounds of coarse rubble were removed, impactite would also be revealed there. This problem of vertical and horizontal distribution needs much more extensive investigation than has been possible up to the present time.

Some shallow excavations in the outer rim slope have shown little or no impactite; others have shown many small bombs. But it is so far impossible to decide whether these differences are due to original variations in the deposit or to surface erosional drift. The latter conclusion seems inescapable in some instances where volcanic ash is mingled with the impactite because the ash deposit came long after the crater was formed. Otherwise, as already pointed out, the two should be mingled in the undisturbed rubble. This has been proved contrary to fact.

DEDUCTIONS

Apparently there was a widespread deposit of impactite mingled with the earlier deposit of ejecta. The only quantitative measurements were made on samples taken in the excavation on the northwest rim; but surface collections indicated at least as great, or possibly greater, concentrations near the base of the southeastern rim at an equal distance from the crest. Digging to depths of 18 inches one and one-half miles northeast of the rim crest showed many small bombs and fragments of slag. Very good samples were found in the vicinity of the silica diggings on the southern rim and farther south.

A few bombs were picked up on the surface on the lower southwestern rim slope, and bombs were found due east of the crater in all places examined where drift sand had not concealed them. The northern sector of the rim has been spoiled for surface investigation by the construction of the new road to the crater. Volcanic cinders were used for this road bed. They were hauled

in the autumn and left exposed all winter before the oil was applied. Strong southwesterly winds scattered them far and wide so that any future investigations of the north rim will have to be by way of excavations.

Spencer (1933b) concluded that the silica glass of the Henbury and Wabar craters indicated that there had been a pool of boiling silica into which

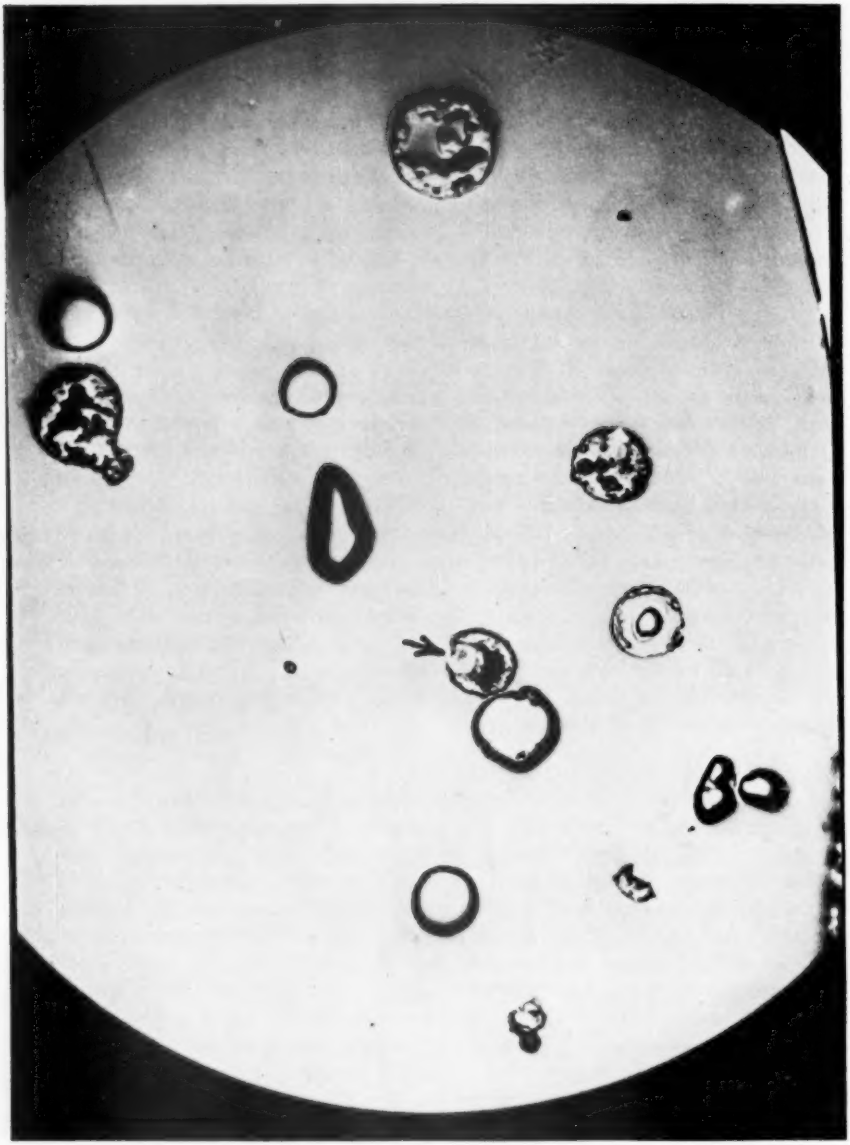

Fig. 4. Some of the smaller bomblets, X 50. Several of these show no vesicles and appear to be glass. The arrow points to a metallic inclusion in a very small bomblet. (Photograph by Dr. George Edwards, University of Chicago.)

fell a drizzle of nickel-iron droplets, condensed from metallic vapors. He also suggested that there would probably be found a wide range of conditions in different craters, and one finds difficulty in visualizing the boiling pool as a source of these bombs at the Arizona Crater. Lechatelierite has been found in the crater pit although it is not known to be very extensive. However, no nickel-iron has been found in samples of lechatelierite that have been examined, to the knowledge of the writer. Barringer (1909) mentions what seems to have been iron and nickel staining but evidently from solutions of these metals. Merrill (1908) describes lechatelierite as a pumiceous glass with no mention of any metallic particles, but he does mention that certain drill holes yielded thin metallic scales. These were never assigned to the lechatelierite formation.

If the lechatelierite in the crater pit represents a boiling pool of silica, this pool could hardly have been the source of the glassy droplets now being discovered, for these are not silica and they are loaded with metallic particles which are never found in the lechatelierite.

One wonders if the bombs were not encountered in some of the drill holes in the crater, but were crushed into unrecognizable fragments. Merrill (1908) speaks of a silico-ferruginous slag, such as it was conceived might result from a mutual fusion of sand grains and meteoric iron:

> "Nothing was found that could be thus positively identified until hole No. 20 was reached, though some of the particles showed in thin-section a very deep green or brownish, blebby glass which it was first thought might be particles of volcanic sand common to the region. A comparison of the two materials did not substantiate this view, and it would seem that such must in some way be connected with the meteoric phenomena, though it was not possible to correlate them absolutely with the nickeliferous granules."

Here the writer believes Merrill actually examined bits of the impactite, probably crushed bombs, from a depth of 640 to 680 feet below the crater floor some 300 feet east-northeast of the main central shaft. They were unable to correlate the nickeliferous granules with the "blebby glass" probably because the two had been separated by crushing drill action. However, this cannot be definitely proven at this late date.

It seems probable that the major portion of the slag that is being found was produced as a splash product of the impact as the meteorite passed through the Kaibab formation. The question then arises why should one not find an even greater amount of true silica glass since the Coconino formation is almost pure silica and is twice the thickness of the Kaibab formation, and since the meteorite is known to have penetrated both formations. Yet the only glass that one can be certain came from that formation is the lechatelierite which seems to occur in comparatively small quantity.

One possible explanation comes to mind, the validity of which rests on the following facts and assumptions: (1) The water table in the area at present is approximately 200 feet below the present floor of the crater which is about midway of the Coconino sandstone. This water table is known to have been much higher in the past and to have been unstable, since lake deposits make up a part of the crater fill below some 30 feet of alluvium and wind deposits. Jakosky (1932) describes these lake deposits as being the playa

type. (2) The Kaibab formation is very compact and practically impervious to water. (3) Opik (1936) has shown that such a meteorite striking at cosmic velocity would develop pressures that exceed the elastic limit, so that both the meteorite and the target may be treated as liquids. (4) The meteorite is known to have penetrated about 1200 feet of sediments (vertical measurement). The Moenkopi and Kaibab beds account for 350 feet of this. The air cap carried by the mass was probably equivalent to another 50 feet of rock, and if the meteorite's approach before encountering the atmosphere was tangential it may have been much greater. Consequently, we may assume that from 30 to 50 percent of the projectile's energy was spent before it entered the Coconino formation. (5) The formations in its path ahead of the invading mass were subject to enormous pressures before they were actually invaded. Boon and Albritton (1938) have estimated that the pressure may have been equal to 25 million atmospheres.

Now, if it be assumed that the water table was approximately at the Kaibab-Coconino contact level, the interstitial water in the porous Coconino was changed into superheated steam well ahead of the meteorite, constituting an explosion, shattering sand grains, and producing the several stages of metamorphosed sandstone; but in the presence of steam which was restrained but not confined, very little of the sand was subjected to sufficiently high temperature to produce lechatelierite. On the other hand, the Moenkopi and Kaibab, relatively dry and being struck with maximum violence, were instantly vaporized or transformed into slag which splattered as blobs and droplets in all directions, coming to rest before the bulk of the ejectamenta landed.

The metallic particles that are embedded in the glass must likewise have been splash droplets from those parts of the meteorite which touched the rock through which it was passing. They are not, therefore, condensation droplets like the metallic spheroids. As already pointed out, the nickel-iron ratio differs from that of the spheroids.

According to this hypothesis, the relative scarcity of silica glass from the Coconino is due to the reduced energy of the meteorite and premature steam explosion together with the cooling action of water vaporization, whereas the scarcity of glass from the siliceous Moenkopi is due to the higher velocity of the impinging mass and its consequent volatilization of the surface formation on contact.

During these stages of penetration the internal temperature of the meteorite was building up to the final grand explosion of the mass itself. It was this event that gave the crater its final form and sent aloft the gigantic metallic vapor cloud from which the metallic spheroids were condensed.

An oxyacetylene flame was applied to some small pieces of the Kaibab formation. The flame was supposed to develop a temperature of 5800°F. or 3240°C. Application of the hottest part of the flame for a period of two minutes produced blebs which looked very similar to some of the impactite bombs. A carbon flame was then applied by substituting a carbon rod for the metal electrode of an arc-welder. This vaporized most of the treated material; the

remainder merely puddled. Perhaps the calcareous constituent of the Kaibab in the vicinity of the meteorite contact was vaporized leaving the magnesium carbonate and silica of the formation to be fused into dolomite-silica-slag.

The Kaibab formation is known to be quite variable as to its content of silica, and judging from its appearance its content of $MgCO_3$ is likewise

Fig. 5. Small impactite bombs in section, X 50. (Photograph by Dr. George Edwards, University of Chicago.)

variable. This heterogeneous composition could account for some of the variability in appearance noted in the material examined. Chemical analyses of the different types may clear up the matter.

NEED FOR EXTENSIVE RESEARCH AT THE ARIZONA CRATER

The discovery here reported brings this crater more closely in line with the calculations of Moulton (1929), Wylie (1933), and others regarding the energy release of large cosmo-terrestrial encounters. It also brings to light an entirely new species of impactite and inevitably suggests the possibility that large impacts may have produced a wide variety of metamorphic products.

Of more immediate concern are a number of questions related directly to the amassing of a more complete assemblage of factual data regarding various aspects of the crater under investigation. The securing of such a body of facts should precede any final effort to round out the picture of such events as produced this outstanding feature of the planetary landscape.

Some of the questions that come to mind are: (1) The areal limits of the dispersal of the impactite. (2) Its horizontal and vertical distribution pattern. (3) Its range of composition. (4) An estimate of tonnage of this material. (5) An estimate of tonnage for the nickel-iron carried by this material. (6) Since the principal formation (Coconino sandstone) invaded by the meteorite is almost pure silica, why do we not find this mineral strongly dominant in the fused product? Is there some better answer than the one here suggested? (7) What is the relation between the metal-free lechatelierite found by Barringer (1909) in the crater pit and the nickeliferous, dolomite-silica bombs here described? (8) Are similar bombs also mixed with the fill in the crater pit? (9) What can be ascertained as to the quantity and distribution of lechatelierite associated with the crater? (10) Why is no nickel-iron found in lechatelierite? (11) Have the metallic spheroids been derived from impactite by attrition or were they a separate product from the moment of formation? (12) In view of the abundant evidence of extreme temperatures produced by this impact, why do the exposed formations of the inner crater wall show no glazed surfaces? (13) Or do they show such glazing in protected spots that have not been found? (14) Is the present spotty distribution of impactite due to the manner of is original dispersion or to its exposure by differential erosion? (15) May there have been atomic disintegration produced by the extreme temperatures of impact here and, if so, is it still possible to demonstrate the fact?

While this paper was in preparation an article by Dorsey Hager (1953) appeared in which its author contends that the Arizona crater is not the result of meteoritic impact but rather that it is the result of a combination of normal geological forces.

Without going into a lengthy analysis of his paper, which consists of an elaborate presentation of geological features spread over an area of some 10,000 square miles, most of which can be considered as related to the crater only on the basis of a forbidding list of assumptions, I submit the following:

Mr. Hager points to the fact that the crater lies in an area some 15 by 120 miles which is beset by sinkholes but fails to point out that the crater bears not the least resemblance to any of these. He points to the existence of many graben some 60 miles northwest of the crater and then *assumes* that four of the thirteen faults in the crater rim are connected through the floor of the crater by concealed faults, thus making it a graben.

He assumes that the crater is underlain by a bed of evaporites and cites the discovery of such underlying beds 30 to 50 miles southeast of the crater; but he fails to note that the several wells drilled on ranches adjacent to the crater encounter neither evaporites nor brackish water, and that the water taken from drill holes or shafts in the crater was never brackish.

Hager assumes also the former existence of a 1000-foot high dome where the crater now is, and to account for this, assumes a buried land mass to the east of the crater, the existence of which is supported only by an aeromagnetic survey which could be interpreted as well on the basis of a normal anticlinal fold.

He asserts that the "rock flour" is mainly just sand. However, he cites no proof. On the other hand, Jakosky et al. (1932) state positively that "the rock flour consists of extremely fine sand which the microscope shows to be angular shreds of quartz." Merrill (1908) states that this material "under the microscope is seen to be composed wholly of the sharply angular bits of quartz derived from the shattering of the individual grains of sand" and publishes a photomicrograph to prove his point. The present writer has also found the rock flour to be mainly angular quartz fragments, very different from the rounded grains of quartz in either the Coconino sandstone or the arenaceous Kaibab formation.

In attempting to depict the fall of meteorites in the area as an event unrelated to the formation of the crater, Hager (1953) reveals a notable lack of familiarity with the behavior of meteorites as they land on the earth (see diagram in fig. 12, p. 847 of Hager's paper).

More important, he failed to discover the metallic spheroids, which we have proven to exist literally in thousands of tons mixed with the soil particles around the crater, and after their discovery had been announced he made no effort to investigate them, but casually referred to them in his paper as something to be expected in connection with any meteorite fall. Actually, none have ever been found in connection with any of the more than 600 falls recorded except in association with craters.

Equally important, Hager (1953) failed to recognize the impactite described in this paper. He built this hypothesis on a long list of assumptions but apparently saw no reason for making a detailed examination of the area under consideration.

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PALYNOLOGY OF THE TAKU GLACIER SNOW COVER, ALASKA AND ITS SIGNIFICANCE IN THE DETERMINATION OF GLACIER REGIMEN*

CALVIN J. HEUSSER

ABSTRACT. Regimen determination for a glacier is based on the amounts of accumulation and ablation taking place during a budget year. The measurement of accumulation is usually made from dirt horizons exposed on the walls of crevasses. Dirt horizons are not always evident, however, and it often becomes a difficult task to determine the amount of nourishment. Because of this, the pollen and spore stratigraphy of the Taku Glacier snow cover was investigated as a possible means for locating the ablation surface of the previous budget year.

Samples in stratigraphic sequence were obtained from eight pits dug in the glacier at elevations ranging between approximately 2000 and 6000 feet. Seventy-five samples were melted and allowed to settle out in pails and the sediments taken to the laboratory for analysis. Total pollen and spore counts were made for each level sampled. Profiles were prepared from these data and comparisons made.

Coated microscope slides were exposed to the air, and spectra for airborne pollen and spores were prepared for most of the flowering period. The interpretation of the profiles is based on these spectra. Meteorologic factors affecting pollen transport are discussed.

Results show: (1) the amount of seasonal accumulation is variable and the depth to the 1951 ablation surface increases in proportion to altitude; (2) autumn snow was the only sediment remaining in the pit studied at the lowest elevation; progressively up-glacier winter, spring, and summer increments become apparent; summer snow was present only in the pit highest in elevation; (3) downward percolation of pollen and spores does not generally occur.

INTRODUCTION

The determination of the regimen of a glacier is based on the amounts of accumulation and ablation measured in terms of water equivalents during a budget year. This regime is established from the volume of accumulation taking place during an accumulation period and the volume of ablation occurring during the following ablation period (Ahlmann 1948, 1953). In order for an advancing glacier to maintain itself, it is necessary that the amount of nourishment in the area of accumulation exceed the amount lost in the area of ablation. This is a positive regime, and the flow of ice from the former area to the latter will enable the glacier to move forward at its terminus. A retreating glacier exhibits the converse of the situation described above; that is, the amount lost in the area of ablation is greater than the accretion in the area of accumulation. This is a negative regime. Any flow is insufficient to replace the loss in the area of ablation, and the glacier terminus retreats. When equilibrium between accumulation and ablation is reached, the terminus becomes stationary.

The measurement of the amount of annual accumulation has generally been made from dirt horizons exposed on the walls of crevasses. Pits have been dug in the glacier in areas where crevasses do not show up even late

* Contribution from the Juneau Ice Field Research Project which is directed by the American Geographical Society through contract with the Office of Naval Research. Snow cover refers to the 1951-1952 autumn, winter, spring, and summer increments. Although it is understood that firnification was going on at the time of the study, this terminology is followed in order to distinguish between the accumulation of the budget year and the underlying firn or ice.

in the ablation period, and the depth to the dirt layers is subsequently measured. This practice is applicable in areas where there is sufficient windblown material present to be distinguished in successive years as dirt horizons. Some areas are not so characterized and as a result the layering of dirt is not evident. Further, in an area of accumulation which is undergoing different intensities of ablation from year to year, the quantity of dust may be so variable as to be often indistinguishable. Sharp (1951a) discusses this difficulty for the Seward-Malaspina glacier system, Canada-Alaska. Under such conditions it is necessary to apply techniques which would designate this annual surface. Pollen studies were therefore made an integral part of the glaciology program of the Juneau Ice Field Research Project. It was anticipated that the pollen content of the snow cover would indicate the seasonal layers and the position of the ablation surface for the previous budget year.

The theory behind the application of palynology to the measurement of annual accumulation may be summarized as follows. The presence of different types of pollen and spores in the atmosphere in varying amounts is related to the phenology of flowering and pollination of plants of the regional vegetation. Autumn, spring, and summer snows will contain pollen grains and spores characteristic of the particular season, but winter snows should theoretically contain no plant remains. Annual ablation surfaces should contain pollen and spores of different seasons since these horizons usually represent the fusion of several seasonal nourishing layers. Pollen abundance should be highest for such surfaces, although it should vary depending on the location of the area in relation to the pollen source and the amount of ablation. Sampling of the snow from stratigraphic sections and subsequent analysis should permit an understanding of the annual accumulation when the snow pollen and spore data are related to aerial spectra for the region.

Studies presented here are introductory for this phase of glaciology as applied to a North American glacier. Original work dates back over 20 years ago to Europe, and the following is a resumé of the literature. The application of pollen analysis to glaciology was first begun in 1932 by Volkmar Vareschi in his study of ice from Grindelwald Glacier in the Swiss Alps (Vareschi, 1935a). During the next two years samples were analyzed from the Aletsch Glacier in the Alps, after which Vareschi established certain facts which enabled him to pursue his studies on a larger scale. These included: (1) There is sufficient pollen in samples of glacier ice of 2-10 dm^3 to permit a statistical study; samples are seldom lacking in pollen and more than 5000 grains per dm^3 were encountered. (2) The preserved condition of the microfossils, especially the small grains, is good, although winged conifers such as fir and spruce are often badly crushed or broken. (3) Average pollen frequency is variable for a given glacier and also variable for different glaciers; further, terminal portions contained many times more grains than the higher firn regions.

This early work was followed by several papers (Vareschi 1935b, 1937) which culminated in a comprehensive treatise dealing with the movement and structure of glaciers from the pollen stratigraphic standpoint (Vareschi,

1942). Studies presented in this latter publication were carried out on the Aletsch Glacier in Switzerland and the Gepatsch Glacier in the Tyrol. No additional work has been published on glaciers by Vareschi, although a summary of his research and its bearing on glaciology has been published by Godwin (1949). No studies other than those of Vareschi are known in the literature.

Pollen stratigraphy of the snow accumulated on Taku Glacier since the close of the 1951 ablation period was determined in conjunction with investigations of the physical characteristics of the snow cover. These latter studies were carried out by Mr. Edward R. LaChapelle of the 1952 party and constitute a record of density, ram resistance, cone hardness, grain size and type, and temperature (LaChapelle, 1954). Evaluation of the data gathered as a result of these joint studies should furnish a clearer understanding of the 1951-1952 budget year accumulation on Taku Glacier. In turn a more accurate calculation of the regimen of the glacier should be possible.

ACKNOWLEDGMENTS

Members of the 1952 party assisted with the digging of pits from which samples for study were obtained; George Argus, James Hickey, John Howe, and Fred Milan, all of the 1952 party, obtained the meteorological record and helped expose coated slides in the ice field; Arthur Gilkey, leader of the party, showed many courtesies and Edward LaChapelle assisted with the pollen downwash experiment; personnel of the U. S. Forest Service in Juneau gave invaluable aid, especially Alva W. Blackerby who exposed coated slides there; the U. S. Forest Service also made warehouse and transportation facilities available; the Tenth Air Rescue Group airlifted personnel and supplies; and John Heusser, my father, constructed the shelter assemblies used in collecting pollen and spores from the air. Laboratory work was conducted at Yale University in the Osborn Memorial Laboratories with the aid of the Theresa Seessel Fellowship.

PALYNOLOGY OF THE AIR

It was necessary to know the seasonal distribution of the various types of pollen and spores in the region of the Juneau Ice Field before an understanding of the pollen stratigraphy of the snow cover could be reached. Prior to conducting his studies on the glaciers in the Swiss Alps, Vareschi (Lüdi and Vareschi, 1936; Vareschi, 1940, 1942) obtained spectra for pollen in the atmosphere throughout the year. In the study presented here, stations were set up in Juneau and in the ice field, 16 miles above the terminus of Taku Glacier and at an elevation of 3875 feet (fig. 1). In addition the 1952 meteorologic record for the ice field was analyzed in relation to the spectrum for that locality.

METHODS

Microscope slides coated with stained glycerine gelatin mixture were exposed during the 1952 flowering period for continuous intervals at the research station in the ice field and on the roof of the Federal Building in Juneau. Stations are 25 miles apart and at a difference in altitude of ap-

proximately 3700 feet. Sufficient glycerine gelatin was applied to each clean slide so that when the mixture was spread out it provided a thin coating over an area that could be completely taken up by a 7/8-inch-square cover glass. The mixture was prepared by gently boiling 28 g of powdered gelatin, 4 g of crystallized phenol, 168 ml of glycerine, and 198 ml of distilled water for 10 minutes. A small amount of basic fuchsin dye was added to the mixture in order to provide a stain for the spores and pollen grains.

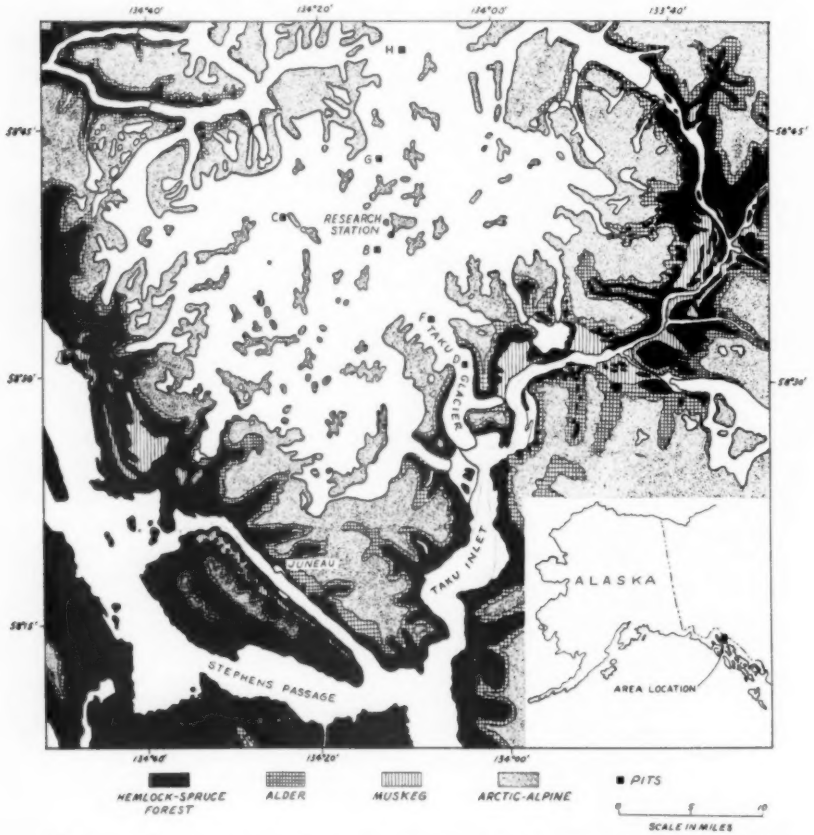

Fig. 1. Sketch map of the Juneau Ice Field showing location of collection stations, pit sites, and generalized distribution of vegetation types. Vegetation has been interpreted from vertical and trimetrogon aerial photographs on file at the American Geographical Society. Map based on that appearing in Geog. Rev., v. 40, p. 195.

Slides were horizontally exposed in shelters similar to that described by Wodehouse (1945). Shelters consisted of two circular aluminum shields, 10 inches in diameter, which were separated 4 inches apart, one above the other, by means of 1/2-inch wooden dowels. At the center of the upper side of the lower shield a grooved wooden block was fastened. The coated slides were

secured in the groove of the block by a fixed metal clip and the entire shelter assembly supported a few feet above the ground by means of an upright 1-inch wooden dowel. Both shelters used in this study were exposed to free air circulation on all sides but protected from vertically falling precipitation by the upper shield.

Exposed slides were replaced by freshly coated slides usually after exposure for a week. Large pieces of dust were removed with forceps and the slide warmed in order to melt the glycerine gelatin and also to drive off moisture which collected. A 7/8-inch-square cover glass was then carefully placed on the mixture. After cooling, slides so exposed were stored in commercial slide boxes which were placed upright in order to keep the slides horizontal. Under room temperatures the mixtures between the slide and the cover glass may run if the box is stored flat with the slides on edge.

Slides were examined in the laboratory, using a compound microscope equipped with a mechanical stage. The entire area of the cover glass was surveyed, and the number of each type spore and pollen grain was tabulated. Low magnification of 100 diameters was generally used to make the total count. A high magnification of 440 diameters was reserved for critical determinations and slides with a profusion of material. Each slide was investigated in this way and the area of the cover glass used as a basis for comparison. Fifteen slides were examined from the research station and represent a period of exposure from 24 May to 13 September. Twenty slides were studied from Juneau. These represent exposures from 15 May to 13 October.

SPECTRA

The schedule of pollination for Juneau may be essentially summarized as follows (fig. 2): (1) poplar (*Populus*) and "conifer complex" pollen (inaperturate grains) in spring, (2) spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), and alder (*Alnus*) in late spring-early summer, (3) pine (*Pinus contorta*), mountain hemlock (*Tsuga mertensiana*), and grasses (Graminad) in summer, and (4) polypodiaceous ferns (Polypods) in late summer-early autumn. The spruce high during the latter interval (fig. 2) is discussed below. The sequence for the ice field is by and large similar (fig. 3): (1) spruce and western hemlock in late spring, (2) alder and birch (*Betula*) in early summer, (3) pine, mountain hemlock, and "conifer complex" pollen in summer, and (4) no late summer representatives in any significant amount. These data are incomplete as periods early and late in the year are absent. Spectra embracing an entire year would be most valuable in the interpretation of the palynology of the snow cover.

The three maxima for spruce on the Juneau slides in August, September, and October (fig. 2) are of interest since by the end of July flowering should have been completed over the altitudinal range of the tree. There are two possible explanations for this. The first is that pollen that had previously settled in the region became sufficiently reworked by wind to register the maxima. Pollen on the slides during these periods of higher counts does not appear fresh. Cells and bladders are commonly darkened and opaque. The periods indicated in figure 2 which preceded the maxima (18-25 August, 8-15

September, and 29 September-6 October) are all associated with high winds in Juneau (U. S. Department of Commerce, Weather Bureau, 1952).[1] A comparison of the sums (miles per hour) of the highest winds during these times with sums for the periods directly following the maxima shows a correlation. The sum for 18-25 August is 102 and for 25 August to 1 September, 100.

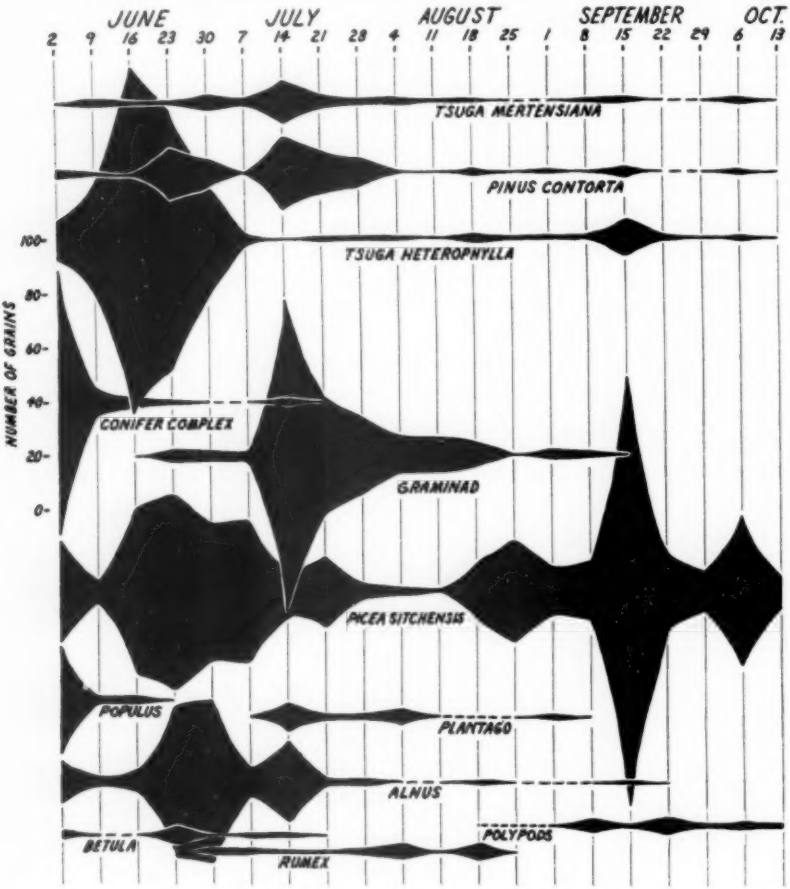

Fig. 2. Aerial spectrum for slides exposed in Juneau.

The amount falls to 79 for 1-8 September while for the period preceding the highest maximum, 8-15 September, it is 160. The amount again declines to 97 for the 15-22 September, but rises to 155 for the last maximum observed during the 29 September-6 October period. Since there is an increase of certain other species to coincide with the spruce maxima, high winds seem to be a logical explanation.

[1] Records are from the Juneau Airport, eight miles northwest of the city; no records are available for the Juneau pollen station.

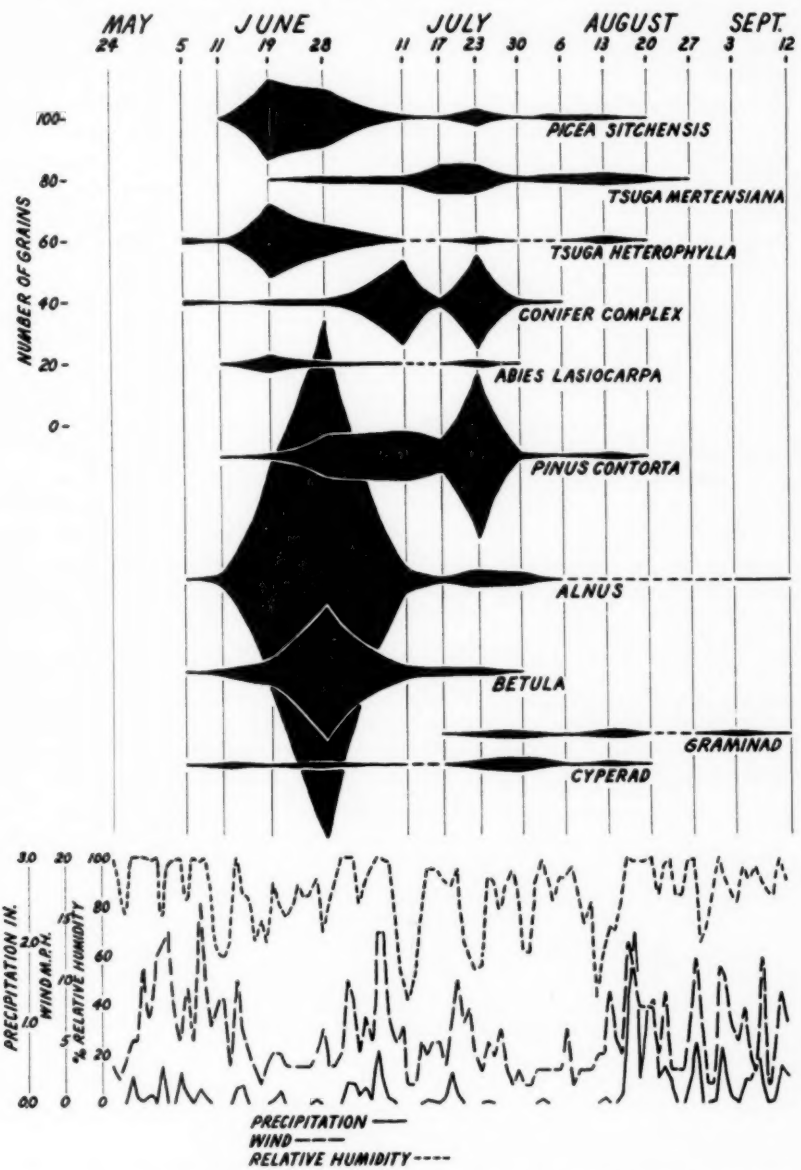

Fig. 3. Aerial spectrum for slides exposed at the research station in the ice field and record of precipitation, relative humidity, and wind for the corresponding period of exposure at the station. Prevailing wind and average relative humidity calculated from six scheduled observations per day at 0700, 1000, 1300, 1600, 1900, and 2200. Average wind from anemometer indicating total miles past station (read daily at 2200).

The second explanation is offered by Mr. Alva W. Blackerby of the Tongass National Forest in Juneau (personal communication). Millions of small moths of the spruce budworm were in the air during this storm period, and appreciable numbers were observed on the ice field. The wing of a moth was found on one slide during examination. These insects may act as a transporting agency under such conditions. High incidence of strong winds during times of maxima, however, is considered a more cogent factor, with the possibility of moths playing a role in transportation of secondary importance.

SIGNIFICANCE OF METEOROLOGIC FACTORS

An examination of the meteorologic record in figure 3 shows that precipitation, relative humidity, and wind were generally higher in late spring and late summer. Pollen was low in late spring, and it was not until 19 June that sufficient quantities were present in the air to be picked up on the slides. This pollen rise occurs following a decline in precipitation, relative humidity, and wind. The striking rise of alder on 28 June follows this interval of low wind and moisture. Alder had decreased by 11 July while wind and moisture had increased. Pollen grains were few for the period 11-17 July while relative humidity was generally high with wind and precipitation low for the same interval. Pollen increased on the slides during the subsequent exposure 17-23 July while there was less humidity and greater wind. With the increase of all three factors from about 13 August to the end of collection in September, very few grains were picked up.

Frequency of wind from a particular direction for given periods is diagrammed by polygons (fig. 4). Polygons are for individual monthly periods as well as for the accumulative record of the entire time of observation. Data for late May indicate a predominant southeasterly wind, and this continues to be the case for June. The prevailing directions for July and August are northwesterly and easterly with an increase of southeast wind in August. The polygon for the first half of September reveals a southeasterly direction for the most part. Examination of the polygon for the overall May to September period clearly shows the prevalence of wind from the east-southeast sector and from the northwest. Northerly and southerly directions have the lowest frequency of prevailing wind, and there is a low number of days with wind from the southwest. A moderate number of days is recorded with wind from the west and northeast. Wind at the research station is largely from British Columbia and the Taku River Valley to the east and southeast. Wind is also frequently from the Berners Bay drainage to the northwest. Winds seldom blow from the direction of Juneau.

This latter fact would explain certain differences between the Juneau and ice field spectra, such as in the amounts of grass, poplar, and birch pollen. It may also explain the absence of spruce pollen in the ice field during the latter half of the collection period when it was abundant in Juneau.

Since easterly and southeasterly winds are usually coincident with precipitation and storminess, while northwesterly winds are drier and fair, it is more likely that pollen reaching the ice field is derived from the northwest.

This would be from the border of the Coast Mountains along Lynn Canal. Also, since local meteorologic conditions will affect pollen settling, the pollen flora in the ice field will vary from one locality to the next and with the distance from the pollen source.

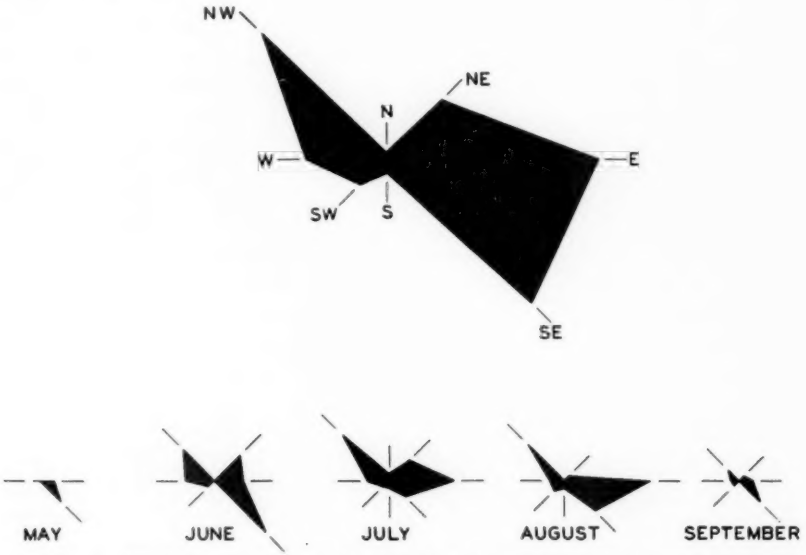

Fig. 4. Wind polygons for 111-day period of observation at the research station in the ice field. Total record is displayed above with individual monthly records as indicated. May and September polygons are partial as a result of fewer days of observation.

PALYNOLOGY OF THE SNOW COVER

Eight pits were studied on Taku Glacier. These were located between approximately 2000 feet on the lower glacier and 6000 feet near the Taku-Llewellyn Glaciers drainage divide (fig. 1). The distribution of these pits was made possible through the use of an M29c oversnow vehicle ("weasel") which greatly simplified the logistics involved in the operation. In this way 75 samples from pits ranging in depth from 9 dm to over 73 dm were gathered.

METHODS

Samples for analysis were obtained in stratigraphic sequence from the walls of pits dug through the snow cover into the underlying firn or ice. Samples were each approximately 1 cubic foot (27 dm^3) in volume and were collected in numbered steel and galvanized pails (2½ gallon size). Pails were washed as clean as possible under such conditions with clear meltwater. This wash water had been obtained by melting snow from a foot or so beneath the glacier surface, allowing the resulting water to settle out for 15-20 hours, and decanting off the sediment-free portion. A round-nosed, D-handle shovel was adequate for cutting out samples from the pit walls. In the deeper pits it was necessary to use a rope and in one instance, an improvised boatswain's chair.

Excavated samples from such deep pits were hauled to the surface with the aid of an assistant. The pails containing the samples were then heated over a Coleman "Handy Gas Plant" and the contents melted. Melting was usually carried on inside a tent where protection was offered from wind, rain, and snow. After the sample was melted, the pail was placed outside on the surface of the snow and covered by a tarpaulin in order to protect the sample from contamination by pollen falling from the air. Samples were then allowed to settle out for periods which depended upon the time available at each locality. The minimum time for settling in the pails was a period of 15 hours, and the maximum was 51 hours. Decanting followed this first settling-out period. The volume of meltwater was thereby reduced, and the residue was transferred to a liter beaker. The sediment settled in the beaker for a minimum of 14 hours and a maximum of 48 hours. The clear meltwater was again decanted. The volume of meltwater after this second decanting was sufficiently reduced so that the residue was poured into an 8-dram glass vial and corked.

Samples from the field were first treated with dilute hydrochloric acid in the laboratory. Considerable quantities of tiny metal flakes had peeled from the galvanized pails during melting of the samples and subsequent sedimentation. These particles had become mixed in almost all sediments and had to be removed. It is recommended in this regard that steel pails be used rather than galvanized ones. The former are more expensive but do not produce the metal flakes on heating. After hydrochloric acid treatment, the samples were centrifuged, washed by shaking in distilled water, and centrifuged again. Dilute potassium hydroxide solution was then added to the sediment in the centrifuge tube and the tube with its contents heated in boiling water for 10 minutes. The sample was subsequently poured hot through a wire mesh sieve in order to remove macroscopic particles. After allowing the sediment to settle for a few moments, the liquid with the smaller-size particles was decanted. Larger inorganics that had passed through the sieve remained behind in the tube. The decanted sample was then centrifuged, washed with distilled water tinted with gentian violet dye, and again centrifuged. Sediment in the centrifuge tube was transferred in a few drops of water to a clean microscope slide by means of a small pipette fitted with a rubber bulb. The slide was warmed on a hot plate at approximately 75°C. and the liquid evaporated to near dryness. Care was taken not to evaporate the material completely. A few drops of clear glycerine gelatin mixture were then added to the sediment, a 7/8-inch-square cover glass placed on the material, and the slide allowed to cool in a horizontal position.

Slides were examined under the compound microscope with the aid of a mechanical stage. High magnification of 440 diameters was used to make counts from pollen-rich samples, and low magnification of 100 diameters was used for material containing few pollen grains. When certain grains were encountered which required closer scrutiny, the 44x objective was swung into place for use with the 10x oculars. Each count was made for the entire area of the cover glass.

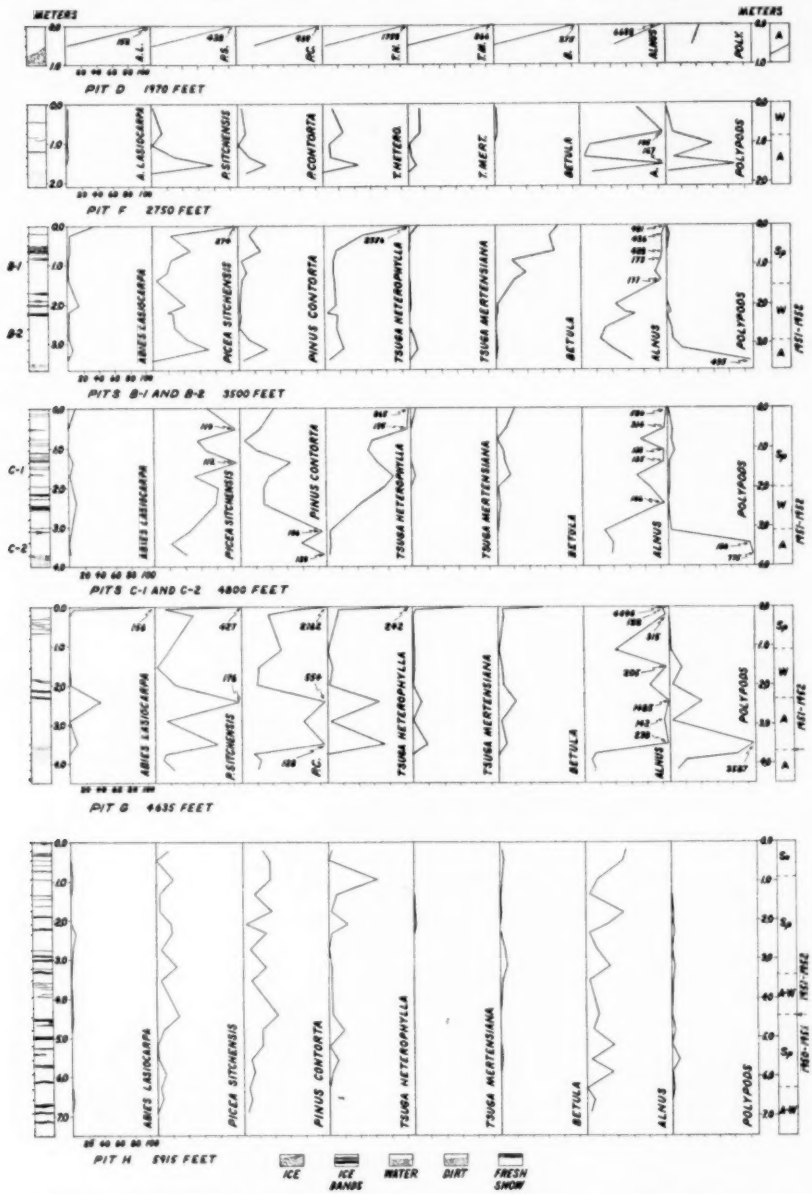

Fig. 5. Stratigraphic sections, pollen and spore profiles, and seasonal increments from pits dug in the Taku Glacier snow cover; A=autumn, W=winter, Sp=spring, and Su=summer; arrow indicates junction of 1951-1952 snow cover and underlying firn. Boundaries between seasonal increments should not be considered as fixed. Four digit and larger three digit figures are approximate and have been computed by sampling unit slide areas, obtaining an average, and multiplying this figure by total unit areas comprising the entire slide area.

SNOW COVER AND POLLEN STRATIGRAPHY

Pit D was dug 9 dm deep on 7 July and is the shallowest of all pits and lowest in elevation. Its location at 1970 feet near the tongue of Taku Glacier (7 miles from the terminus) and in the vicinity of the receding snow-ice line explains the shallow depth. No structures were encountered in the snow cover. The depth to the ice basement underlying the snow in the pit studied was quite irregular. Ice was coarse-grained and dirty. Five snow samples were taken, but three of these were lost in shipment from the ice field to the laboratory. Analyses for the remaining samples, however, are plotted in figure 5 and are interpreted to indicate autumn snow. Values at the surface are generally high, decreasing sharply at 5 dm. Fern spores show little change in number at the different levels. The number of alder grains counted (6688) from the surface sample is the highest for all samples of the entire study.

Pit F at 2750 feet and approximately 5 miles up-glacier from pit D was the next higher pit studied. Samples were collected on 9 July to a depth of 21 dm. The stratigraphic section (fig. 5) shows an ice band at 12 dm and a few stringers higher up. The interesting feature of the section is the englacial water table at 17.5 dm. Because of the difficulty involved in obtaining deeper samples and the considerable possibility of contamination, sampling was discontinued after penetrating the water layer to a depth of 3.5 dm. Unfortunately the surface sample and that from 4.5 dm were lost in shipment. Analysis of remaining samples discloses low numbers of grains for the wet snow at the base of the section studied. Above this there is a general increase in abundance, followed by a decline which in turn is followed by a general rise. The latter rise is well marked in alder, but does not show up in the ferns. This section is considered to consist of autumn and winter snow layers, spring snow having already ablated.

Pits B-1 and B-2 were excavated 5 miles up-glacier from pit F and were about 30 yards apart at an elevation of approximately 3500 feet. Pit B-1 was made on 26 June. It was the first pit dug of the series. Pit B-2 was made on 29 June. This latter pit was dug to extricate the oversnow vehicle which had been cached at the close of the 1951 season of the project and subsequently buried by snow. Pit B-2 was of considerable value since it served as a check for the amount of snow remaining above the 1951 annual ablation surface. The lower part of B-1 and the upper part of B-2 were correlated on the basis of depth and corresponding ice bands. Figure 5 shows the broken stratigraphic column to a depth of 37 dm with the portions contributed from each pit. The B-1 section contains a group of bands between the surface and a depth of 1 meter with one band a centimeter in thickness at 6.5 dm. Narrow bands wedge off at 8.5 and 17 dm. In the B-2 section a prominent 5 cm-thick band occurs at 22 dm with a centimeter-thick band at 20 dm. A dirt zone is conspicuous at the base of the column.

The conspicuous features of the profiles (fig. 5) are the abundance of fern spores in the basal dirt zone and the prominence of most species and genera in the upper levels with only a few fern spores. Analysis of the 5 cm band at 22 dm does not indicate any increase in grains by comparison to

levels immediately above or below the band. Snow in the section originated in autumn, winter, and spring. It is of interest to note that a *Pediastrum* colony was observed in the surface sample from pit B-1. Samples from 5 dm and 17 dm in the B pits were not at hand for analysis.

Pits C-1 and C-2 were excavated at 4790 feet at a distance of 7 miles to the northwest of the B pits. This locality is at the northern edge of the high plateau which drains westward, in part, to the Herbert and Mendenhall Glaciers (see fig. 1). Pit C-1 was excavated on 1 July and C-2 on 17 July. The 40 dm section in figure 5 is a composite of the two correlated columns for the individual pits. Numerous bands are distributed throughout the C-1 column with the following conspicuous: 1.5 cm at 21.5 dm, 1 cm at 24.5 dm, and 2 cm at 25 dm. No bands were observed in the C-2 pit. A dirt zone was encountered at 37 dm. Two centimeters of fresh snow fell during the excavation of pit C-1.

The presence of fern spores in abundance in the dirt zone of pit C-2 is similar to that in pit B-2. In addition, numerous pine grains are present. Alder, western hemlock, and Sitka spruce increase toward the upper levels of the profiles while pine decreases. Ferns also decline upward, although their decline is much sharper above the lower sampling levels with a few spores present thereon to the surface. Sixteen spores of club moss (Lycopods) and 22 grains of willow (*Salix*) were counted at the 37 dm level where high counts of fern spores were made. No data are available for the 2.5 dm and 28 dm levels. Autumn, winter, and spring increments are interpreted.

Pit G was located at 4635 feet, 8 miles northeast of the C pits, 7 miles north of the B pits, and 8 miles south of the Taku-Llewellyn Glaciers divide (fig. 1). Samples were collected from this pit on 12 July to a depth of 45 dm. The interface between clean and dirty sediments occurred at 35 dm (fig. 5). Dirt diminished beneath this level. A concentration of ice bands was present between the surface and a depth of 1 meter. A few bands were located just above 20 dm and a short distance below. No structures other than these were observed in the pit section studied.

Numbers of pollen grains and spores are relatively low for the two bottom samples. Fern spores increase sharply above these layers, although there is little change in the numbers of pollen. Ferns reach a maximum at 35 dm and subsequently decline while pollen shows an overall rise. Two layers with abundant pollen are evident at 24 dm and 35 dm. It should be noted that 55 spores of club moss, 13 willow grains, and 4 Compositae grains were found at the 35 dm level, whereas none of these occur at 24 dm. Above these levels profiles generally record a decline followed by a rise with maximum numbers at the surface. Fern spores were absent above 11 dm. Thirty-five caryophyllaceous grains were counted from the surface sample. These were not encountered in such a high number in all samples from the pits studied. The 4.5 and 8 dm levels were not counted. Autumn, winter, and spring layers are depicted.

The final pit H was located at 5915 feet close to the Alaska-British Columbia boundary and near the crest between Taku and Llewellyn drainage. This

is approximately 7 miles north of pit G. Pit H was the deepest pit dug and reached to a depth of 73.2 dm on 14 July. Numerous bands are distributed throughout the section with outstanding ice layers at 45 dm (2.5 cm thick) and at 50 dm (5 cm thick). Elsewhere bands are no more than a centimeter in thickness. Throughout the section no dirt level or zone was noted which could be designated as the position of the old annual ablation surface beneath new snow accumulation.

Spores and pollen grains are relatively few in this section, and no count was made higher than 63 grains for any pollen at any horizon. Alder and western hemlock show maxima in the first meter and are prominent in the second meter. Maxima for pine and spruce are at the 44.4 dm level. These pollen decline below 44.4 dm, whereas western hemlock registers a small rise, and alder is most abundant with two notable peaks. Birch and ferns are sporadic in the section and show no specific trends. Mountain hemlock is barely represented. Data for the 39.6 dm and surface levels are unfortunately missing.

The 1951-1952 snow cover above 44.4 dm is interpreted on the basis of pollen content to consist of autumn-winter, spring, and summer increments. Spring and winter layers are below 44.4 dm. It should be noted that the ram penetrometer and density studies made by Mr. LaChapelle at this site indicated the position of the old 1951 ablation surface to be at approximately 54 dm. This conclusion was drawn on the evidence of an increase in average ram resistance (snow hardness) at 52 dm and an increase in density at about 53 dm.

PROBLEM OF POLLEN AND SPORE DOWNWASH

Vareschi (1937) demonstrated that downwash does not occur from upper to lower layers. This conclusion was reached in the study of a section from the Swiss Claridenfirn. Samples from two levels a decimeter apart showed the upper sample to contain over 36,000 grains, whereas the lower contained only a single grain. The upper pollen-rich sample was obtained from a level which was interpreted to represent four years of accumulation which had been reduced to a single horizon as a result of excessive ablation. A large quantity of yellowish dirt denoted the upper level, and meltwater had caused some of the dirt to be carried downward to stain the area where the lower sample had been obtained. It would be thought that such meltwater movement would affect pollen grains and spores as well as dirt particles. Evidently such was not the case, and the fine fissures between crystals differentially separated the inorganics and the pollen. Vareschi found that the particles that had moved were only 2-3 mu whereas pollen in the upper layer was 16-140 mu.

A downwash experiment was carried out on Taku Glacier. Two funnel-type meltwater pans previously described by Leighton (1952) were secured in the roof of two niches recessed in the wall of a pit dug in the glacier at 3500 feet in elevation. Pans were situated at the 6 dm and 150 dm levels with the edge of each about half a meter from the face of the pit wall. Meltwater from the pans was directed by means of rubber tubing into covered pails placed below each pan. The experiment was conducted for a week. Results for the

lower pan are: 2 grains of spruce, 2 grains of pine, and 1 grain of western hemlock. Rapid ablation of the glacier surface during this period caused the upper pan to dislodge before any sample could be obtained.

This experiment is admittedly inconclusive, although the presence of five conifer grains would suggest that a certain amount of downwash occurred. It may be noted that these grains varied in size between approximately 60 and 90 mu, and no small-sized grains such as those of alder or birch were observed. It is possible that the grains counted represent contamination. Of interest is the analysis of the 5 cm ice band from 22 dm in pit B-2 (fig. 5). A lower number of grains is present in the band by comparison to samples analyzed from above or below. If meltwater carries pollen downward, it would be expected that grains would become concentrated in the band since the band probably represents a winter ablation surface which became thickened by spring meltwater freezing at depth. Such pollen concentration, however, was not found.

The profiles in figure 5 show examples somewhat similar to the situation described by Vareschi. Pit G at the 35 dm level contained 3587 fern spores, but 2.5 dm below only 87 spores were counted. Similarly striking are the numbers of alder and pine grains between the surface and 0.5 dm. Pine and alder at the surface are respectively 2162 and 4494 grains; at 0.5 dm these numbers decline to a corresponding 76 and 188. Surface samples may not represent a valid case since they were from snow which was not subjected to melting and percolation for so long a period as samples at depth. Samples from the surface and 0.5 dm below were collected on 12 July, approximately two weeks after alder had reached its peak (see fig. 3). This length of time should be ample for downwash to occur, although the sharp difference between numbers at the two levels suggests that little or none had taken place.

Analysis of the data given by Vareschi in this regard and those reported here would indicate that the percolation of pollen and spores in meltwater does not generally take place. Under certain conditions there may be some infiltration downward. The size of interstices between crystals is probably the most important limiting factor.

DISCUSSION

The superposition of seasonal snow and its demarcation by means of pollen and spore content form the foundation for the interpretation of the annual accumulation. Aerial spectra, however, lack winter, early spring, and late autumn aspects. The presence of certain pollen and spores throughout the accumulation then suggests that: (1) these never cease settling from the air during the year, and/or (2) there is downward movement of the microfossils in percolating meltwater.

An examination of the aerial spectrum presented by Vareschi (1942) discloses that the period of pollen settling is much more extensive than the period of pollen production (dispersal). Particular pollen such as that of pine and alder was observed to settle from the atmosphere throughout the year, although production occurred during only three to four months. This fact would imply that it is probable that pollen falls on the Juneau Ice Field

over the entire year. It is otherwise difficult to explain the large numbers of pollen in so many layers of the snow cover. It has been pointed out that downwash of grains does not generally take place. With this information in mind, the pollen and spores in figure 5 were interpreted to be representative of the layer in which they occur. There was then little or no translocation from the position where they were originally incorporated in the snow cover.

Pertinent in this regard is the pollen rise in the 1951 autumn layer in pit G (fig. 5). It would seem that a spring-summer period were depicted. The abundance of fern spores, however, intimate that this is not the situation. Ferns sporulate during late summer and autumn (fig. 2). These spores and the winter low in the overlayer establish the snow as autumnal. Further, comparisons with profiles from nearby pits help confirm this conclusion. The presence of large amounts of pollen in the autumn snow may be a result of high winds which effected the reworking of previously settled pollen. This condition was evident in the late summer and early autumn of 1952 as shown in the aerial spectrum for Juneau (fig. 2).

The quantity and type of pollen and spores settling out of the air in different parts of the ice field over the time of sampling are variable. This can be seen from surface samples taken at the pit sites (fig. 5). Pollen dispersal is dependent on wind and moisture. Also, collections were made from 26 June to 17 July during which period the quantity of different pollen types in the air changed (fig. 3).

Depths to the 1951 ablation surface in the pits studied increase with altitude. A comparison of the sections from pit D at the lowest elevation to pit H at the highest shows a progressive increase in the amount of accumulation. Pit D had only autumn snow remaining when samples were collected. Winter and spring layers had previously ablated. The next higher pit F was dug from autumn and winter snow, and no spring snow remained. Pits B-1 and B-2 which are higher in elevation contain autumn, winter, and spring snow. The low counts for the dirt zones in pits B and C indicate that only the upper portion of the zones was reached. Pit H contains the greatest amount of accumulation. This is the only pit with summer snow.

The different depths of seasonal snow reflect local meteorologic factors affecting snowfall and ablation. Precipitation which varies over the ice field and down-glacier winds and eddying currents which cause the formation of drifts and wind-scoops determine the accumulation. In addition, compaction influences the seasonal amount of snow. Pits C-1 and H have larger amounts of spring snow whereas pits B-1, B-2, and G have equal amounts of autumn, winter, and spring snow. Pits C and H have more spring accumulation as a result of less ablation and/or greater spring snowfall.

The designation of the 1951 ablation surface for pit H at 44.4 dm does not agree with the 53.5 dm depth arrived at as a result of analyzing the data on density and snow hardness (LaChapelle, 1954). The reason for this lack of accordance is not clearly understood. The maxima for spruce and pine at the 44.4 dm level are the basis for concluding that the annual surface rests at this level. Peaks for alder below this depth are interpreted as spring 1951 and are comparable to the peaks for spring 1952 in the upper part of the

profile. Assuming the 53.5 dm level to be the 1951 ablation surface, there is little in terms of pollen evidence to agree with this. A possible explanation for the 9 dm discrepancy is that degeneration occurred to almost a meter below the pollen-interpreted 1951 ablation surface. Density and snow hardness figures are lower in the layers immediately below this horizon. The 1951 ablation was more pronounced than in previous years of the project or in 1952, and it is likely that degeneration occurred to a greater depth than usual. Of significance in this discussion are the density profiles given by Sharp (1951b) for the firn of upper Seward Glacier, Canada. Density values in the vicinity of the annual dirty layer decrease conspicuously. Although these values generally increase with overall depth, they decrease when the annual dirty layers are reached. If this explanation is correct, then the change in physical characteristics which occurred at the 53.5 dm level occurred in spring sediments.

As stated previously, the studies presented here are experimental and are subject to human and technical errors. In that they are also introductory, it is anticipated that future work may resolve these errors and overcome certain shortcomings that are not yet apparent. Certain features of the technique such as the amount of pollen downwash are not fully understood. Moreover, the palynology of the air needs greater understanding before a thorough interpretation of the annual accumulation can be made. Eventual clarification of these problems will allow a more precise evaluation of the palynology of the glacier snow cover and its relation to regimen studies.

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A FLOW CAST OF VERY RECENT DATE FROM NORTHEASTERN WASHINGTON

CLIFFORD A. KAYE AND WALTER R. POWER, JR.*

ABSTRACT. An example of gross bedding distortion of very recent date is cited with a view to emphasizing that these features do not essentially originate under glacial climatic conditions. The mechanism responsible for this type of disturbed bedding is thought to be the failure of a weak muddy stratum under the weight of a freshly deposited sand layer.

In view of the growing frequency with which grossly distorted bedding in Quaternary sediments is being attributed to the effects of ground ice and periglacial conditions in general, it is worth considering an example of bedding distortion of very recent date that is not associated with ground ice.

During a deep draw-down of Franklin D. Roosevelt Lake (the reservoir of Grand Coulee Dam) in the winter of 1951-1952, the writers observed a "layer" of much disturbed clayey silt in deposits formed since the reservoir was first filled in 1941. These silt deposits comprise part of a delta that had been built into the reservoir at the mouth of Harker Canyon on the Spokane River arm (the lower part of the Spokane River valley tributary to the Columbia River). There seems little doubt of the contemporaneity of these deposits with Lake Roosevelt, and their discordant contact with the older prelake sediments, on which they lie, was easily established in the field. The structure of the delta was well exposed in the walls of a gully then being eroded by Harker Creek, which was entrenching itself into its own delta, owing to the temporary low lake level. In addition to this dissection the stream had cut several terraces that probably recorded stages in the lowering of the lake. A total thickness of about 40 feet of *horizontally bedded* silts, sands, and gravels were exposed.[1]

A few feet below the surface of one of these terraces, a thin bed of clayey silt had gross convolutions in its upper surface, although its base was undisturbed and was conformable with underlying gravel. The accompanying photograph shows that the convolutions are rather regularly spaced at about one-foot intervals. Between the sharply convoluted waves of clayey silt were pockets of medium-grained sand whose stratification, like that of the silt, was disturbed to conform to the outline of the convolutions. This sand and clayey silt complex was sharply terminated above by a horizontal bedding plane.

The process responsible for this perturbed layer is no mystery. Shrock (1948, p. 156-162) fully describes these features and their probable origin under the term *flow casts* and figured several examples that resemble the one under consideration. Essentially, the genetic conditions indicated by flow casts in general and the Lake Roosevelt example in particular are, according to Shrock, a soft weak stratum which fails beneath the weight of an overlying nonrigid stratum (usually sand). In the Lake Roosevelt example, the weak layer is represented by the clayey silt, which originally must have formed a muddy lake bottom. Onto this bottom a layer of sand was rapidly deposited.

* Publication authorized by the Director, U. S. Geological Survey.

[1] The great thickness of topset bedding in deposits of deltaic origin seems noteworthy and suggests that the continually fluctuating lake level was a strong controlling factor during the construction of this delta.

probably by a sudden increase in the discharge of Harker Creek. The nearly liquid bottom mud was unable to support the sand surcharge and in consequence the sand layer foundered into the mud, breaking up into isolated units and cells in so doing, and squeezing up the mud, which it now displaced, as complicated intrusions along breaks and weak places in the foundering sand layer.

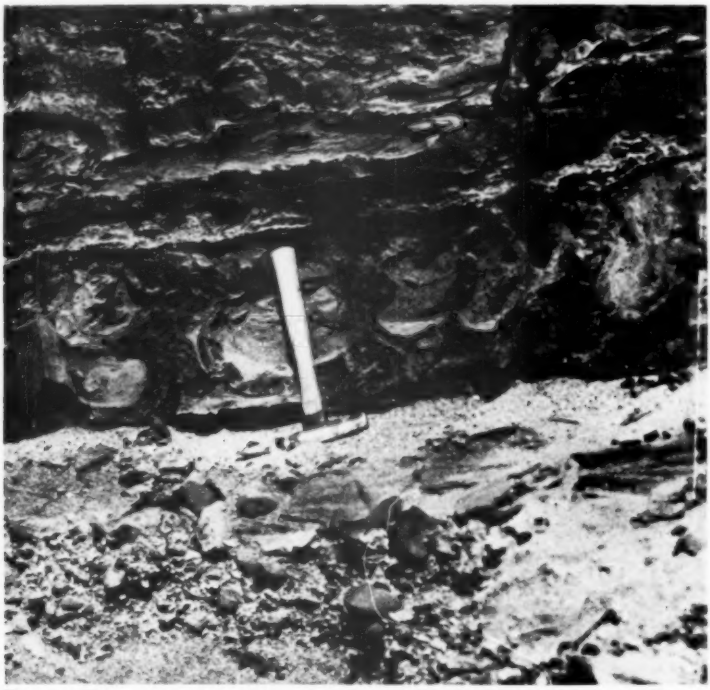

Fig. 1. Flow cast in very recent deltaic sediments, Lake Roosevelt, Washington. The dark distorted layer is a clayey silt. Pockets of sand lie between the convolutions.

The distortion of a weak stratum beneath a nonrigid surcharge is particularly well demonstrated by this Lake Roosevelt occurrence, pointing to the need for caution in ascribing similar features to the special conditions brought about by glacial climates and ground ice.

Reference

Shrock, R. R., 1948, Sequence in layered rocks: a study of features and structures useful for determining top and bottom or order of succession in bedded and tabular rock bodies: New York, McGraw-Hill Book Company.

U. S. Geological Survey
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REVIEWS

The Conduction of Electricity through Gases, 3d ed.; by K. G. EMELEUS. P. x, 99; 37 figs. New York, 1951 (John Wiley & Sons, $1.50).—It is a pleasure to report a new edition of this valuable book. As is characteristic of the Methuen Monograph series, it provides a simplified introduction to the field of gaseous conduction.

The length of the text is indicative of the conciseness of presentation. Descriptions are brief, but sufficiently clear to give at least a qualitative understanding of the phenomena. One might wish that the theoretical aspects of certain sections had been considered in more detail. It is unfortunate that the text does not give credit for the experimental work, nor provide references for the tabulated data.

In the appended bibliography the author has listed papers which will provide additional information about each section of the work, as well as several extensive monographs which he has found "useful."

The book is particularly adapted to the needs of the student, providing the background required to pursue work in many related fields. This group of non-specialists should be particularly pleased that the monograph has been brought up to date.

DON E. HARRISON, JR.

Basic Methods in Transfer Problems—Radiative Equilibrium and Neutron Diffusion; by V. KOURGANOFF with the collaboration of I. W. BUSBRIDGE. P. xv, 281; 61 figs. Oxford and New York, 1952 (Oxford University Press, $7.00).—This book belongs to the domain of applied mathematics. It deals with the restricted problem of Milne, that is to say, the steady-state flow of radiation through a stellar atmosphere. Although many of the results are applicable to the steady-state diffusion of neutrons through a (non-absorbing and non-multiplying) medium of large dimensions, these diffusion problems receive so little attention that their mention in the subtitle is hardly justified. The introductory chapter develops the physical foundations of radiative transfer along strictly phenomenological lines, and without inquiring into the physical significance of the basic postulates, namely, that the material is "gray" (absorption coefficient independent of the frequency) and in local thermodynamical equilibrium. With these postulates the problem of radiative equilibrium is reduced to the study of Milne's integral equation or of the equivalent integro-differential equation. The main part of the book consists of a rather exhaustive discussion of all methods successful in the solution of Milne's problem, including the practically important approximate ones. To the latter the principal author of this book has made copious contributions. He has also added to the mathematical theory of the exponential integrals and certain related functions, which appear everywhere in the theory of radiative equilibrium; two appendices give formulae and tables of such functions, many of them not previously published. The final section of the book deals with the present status of the non-gray case of radiative equilibrium. Here the treatment necessarily is more sketchy; for this problem is still unsolved.

The authors are to be commended for their unrelenting efforts to keep apart the physical and mathematical aspects of astrophysical theory, and to present the latter with a maximum of clarity rarely aimed at. Their pedagogical skill stands out in the exposition of Ambarzumian's theory of scattering, which is not readily accessible elsewhere, and of its generalizations by Chandrasekhar, notoriously difficult subjects. To students of astrophysics, now obliged to acquire some mastery over considerable stretches of mathematical territory, this book is a boon. It is to be hoped that someday other branches of theoretical astrophysics will benefit from Dr. Kourganoff's gifts as an expositor of mathematical theories.

RUPERT WILDT

Micrometeorology, A Study of Physical Processes in the Lowest Layers of the Earth's Atmosphere; by O. G. SUTTON. P. xii, 333; 35 figs., 31 tables. New York, 1953 (McGraw-Hill Book Company, $8.50).—The subtitle admirably describes the field of this book (following usual practice, the microphysics of clouds is not discussed). Each main theme, laminar and turbulent flow, radiation, temperature fields, wind structure, diffusion, and evaporation is carefully developed from basic theory; the limitations and applications of the basic theory are then explained. Most of the material has been available, scattered though scientific papers; but because of the author's clarity of expression, much of it achieves a new vitality and usefulness.

The author has here covered the same field as Geiger in *Climate Near the Ground*, but the books are not substitutes for each other—rather they form a very fine complement the one to the other. Anyone who has read one should read the other.

Meteorologists, fully familiar with Professor Sutton's fine work in this field, will anticipate the value of this book. But we should particularly like to draw it to the attention of biologists, agricultural workers and those interested in phenomena taking place at or near the Earth's surface. Here are tools which could add greatly to precision in their work.

Altogether a fine book well published.

ERNEST F. THOMPSON

Understanding the Weather; by T. M. LONGSTRETH. P. viii, 118; 8 plates. New York, 1953 (Macmillan Company, $2.50).—An enjoyable and profitable evening's reading. It is hoped that other authors can learn from Mr. Longstreth that popular writing need not be journalese and that a thorough personal knowledge of one's subject is no bar to simplicity of expression. The style, organization, and illustrations are excellent. An admirable popular book on the weather.

ERNEST F. THOMPSON

Dynamical Oceanography; by J. PROUDMAN. P. xii, 409. London and New York, 1953 (Methuen & Co., and John Wiley & Sons, $8.50).—This is a clear exposition of the basic mathematics of modern physical Oceanography. The fundamental equations for dealing with hydrodynamics on a rotating sphere are presented in the first few chapters. From there on these equations are elaborated and applied in dealing with a large variety of physical problems in Oceanography—ocean currents, waves, tides, wind action on water, turbulence, and thermodynamic circulation in the oceans. From a dull beginning the book improves, chapter by chapter, reaching a peak of excellence in the discussion of tides. Because Professor Proudman is such a fine mathematician the treatment is surprisingly simple and can be followed by anyone with a sound knowledge of the calculus.

Each chapter contains a brief historical summary of the development of an idea and a short selected bibliography. To the nonmathematician—greatly impressed by the mathematico-oceanographic developments of recent years—it will come as a shock to see how much of the really important concepts was learned long ago and how seldom the impressive work of recent years has materially added to our knowledge. It is hoped that the clarity with which this author expresses himself and the simplicity with which he solves practical problems may inspire some of our brilliant young men to spend at least some of their effort on real oceans.

The only book with a similar title is Defant's unsatisfactory *Dynamische Ozeanographie*. In the present book some figures are unsatisfactory, typographical errors occasionally occur, and once in a great while the author produces one of those sentences of horrible complexity. But if we wished to quarrel with Professor Proudman, we have grounds in that he has kept us waiting so long for the most-needed book in oceanography. We must however forgive him because of the masterly way in which he has completed his task —one of the really important books in the field in this century.

ERNEST F. THOMPSON

A Bibliography on Meteorites; HARRISON BROWN, editor; GUNNAR KULLERUD and WALTER NICHIPORUK, associate editors. P. viii, 686. Chicago, 1953 (The University of Chicago Press, $10.00).—The growth and maturation of active interest in the science of meteoritics, especially within the last century, is uniquely recorded in this bibliography of the world literature on meteorites, as shown by a consideration of the number of entries for successive centuries. The 8660 references of this book are distributed as follows: 1491-1499, *7* entries; 1500-1599, *18*; 1600-1699, *27*; 1700-1799, *107*; 1800-1899, *4497*; 1900-1950, *4004*. Although examples from the literature of antiquity are not included some early translations from the 15th century are given.

The references to the literature 1491-1950 are listed chronologically and continuously. For each entry a unique identifying reference code-number appears prominently in the left margin. This symbol consists of three elements

separated by hyphens: year of publication—initial letter of the (senior) author's surname—a serial number indicating the order of that citation within the year. In cases of doubtful or unknown authorship the second element is omitted. This seems unfortunate because it might lead to confusion when a reference to a work is made by use of the code. Some neutral symbol might easily be inserted in place of the missing letter.

The direct references (p. 1-571) include listings of abstracts, translations, and reviews. These are written in the original language transliterated in the Roman alphabet where applicable, and translated into English, French, or German from most other languages. The second part of the book (p. 572-646) comprises an author index listing below each author's name the chronological code-number from the master list. An index of the journals forming the bibliography makes up the final part of the volume (p. 647-686).

In the introduction the editors express their intention of following this with several volumes dealing with the properties of meteorites; listing the falls and finds in alphabetical, chronological, and geographic arrangement; recording chemical analyses and locations of meteorites in collections; and giving a general index. References in these projected volumes will consist of the code-numbers established in the present volume. When this work is completed it will stand as the most comprehensive and definitive modern source of reference on the subject.

This bibliography is the result of exhaustive research by many people; they have earned the respect and gratitude of interested scientists. Inasmuch as the future publications will be keyed to this volume it is an especially valuable reference tool in the field of meteoritics.

KURT SERVOS

Catalogue of Meteorites; by G. T. Prior. Second edition, revised and enlarged by M. H. Hey. P. xxviii, 432. London, 1953 (Printed by order of the Trustees of the British Museum, £3.10.-).—Prior's valuable catalogue of meteorites was first issued in 1923, and has been supplemented by two appendices (1927 and 1940). This is a whole revision (to December 1952) of the catalogue, rather than a third appendix. The scope exceeds that of the earlier edition in including references to all authentic meteorites, *even if no material is preserved*. A short history of the British Museum Collection, and revised tables of statistics in the Introduction add to the usefulness of this book. In the main body are recognized 1502 meteorites, plus 200 more classed as "doubtful" or "paired"; data given for each are as follows: name, locality (with latitude and longitude if known), date, synonyms, classification, details and original weight, references, present repository (other than British Museum) of main masses, and a list of specimens in the British Museum. The systematic study of meteorites thus achieves a most important forward step.

HORACE WINCHELL

Anleitung zu optischen Untersuchungen mit dem Polarisationsmikroskop, 2d ed. revised; by MAX BEREK (1886-1949), from first edition by Friedrich Rinne (1863-1933) [C. H. Claussen, A. Driesen and S. Rösch, editors]. P. xiii, 366; 285 figs., 21 tables in text. Stuttgart, 1953 (Schweitzerbart'sche Verlagsbuchhandlung, DM 29.00).—This book, by one of the world's widely recognized experts in the field of practical optical design, comprises 15 chapters with 53 subtitles. The new edition has been divided into two parts, the first (p. 1-190) intended for those whose work requires less thorough knowledge of crystallography, and the second (p. 191-355) for mineralogists, petrographers, and chemists. Parenthetically we might wish that *all* mineralogists, petrographers, and chemists could be made equally aware of *all* the material in the first part of this information-packed book!

The whole treatment is thorough and compact; general phenomena of light passing through all types of media are presented early (p. 1-16); there follow sections on polarizers, analyzers, the polarizing microscope, specimen preparation, orthoscopic observations, relation of optical properties to the structure of materials, and simple orthoscopic measurements; the second part of the book treats stereographic projections, the optical indicatrix and its relation to crystal symmetry, conoscopic interference figures, practical techniques for determination of optical constants (including 35 pages on the universal stage), observations and measurements in vertical reflected light, the same in oblique reflected light, and suggested exercise materials for study. An eleven-page index together with the five-page table of contents will enable readers to use this book efficiently for reference purposes; its completeness and logical approach should recommend it to all students in science who desire to apply the polarizing microscope to their special problems.

HORACE WINCHELL

Manual of the Polarizing Microscope, 2d ed.; by A. F. HALLIMOND. P. 204; 92 figs. + 9 in appendix. York, England, 1953 (Cooke, Troughton, and Simms, Ltd., 15 shillings, postage paid).—This new edition of Dr. Hallimond's book has nearly double the thickness of the old, largely by the addition of chapters on special procedures made possible by new accessories or improvements to the Cooke line of microscopes. Old chapters showing substantial increases are those on determination of path-difference, and on the theory for reflected polarized light.

Primarily written for those using Cooke microscopes and accessories (which are well described), this book is nevertheless generally useful in presenting from a new viewpoint the operations involved in petrographic, chemical, and ore microscopy.

HORACE WINCHELL

Verfärbung und Lumineszenz; by KARL PRZIBRAM. P. xiii, 275; 69 figs., Vienna, 1953 (Springer-Verlag, $8.25).—In this book, *Metachrosis and Luminescence*, the author has presented a survey of that branch of mineral physics which is devoted to the study of color, color changes, luminescence and pleochroism. It is a compactly written and well-ordered synthesis of

important, pertinent research published in German, French and English. As a member of the Austrian Academy of Science, Doctor Przibram has spent twenty years in scientific investigations which have made him an authority in this field. He is therefore qualified in a special way to evaluate the vast literature and to gather the best information into a well-rounded survey of the various aspects of this interesting and increasingly more important study.

Dr. Przibram has divided the book into two parts. The first consists mainly of a theoretical presentation of the subject and the experimental data upon which the theory is partially based. It contains, in addition, a brief introductory historical survey of the field and discussions of experimental methods by which color transformations and luminescence are produced. Especially helpful to the student will be the author's clear distinction between the factual and hypothetical information presented.

The second part of the book is devoted to color, color transformation, luminescence and pleochroism in natural minerals. The author has done a great deal of research, especially on halite and fluorite, and consequently treats these minerals at some length in the text. He discusses more briefly other halides, a number of selected oxides, silicates, carbonates and sulfates. In addition a short discussion is accorded to sphalerite, the only sulfide treated, to a few phosphate minerals and to soda niter. Except for the halides the author's treatment is essentially that of a series of concise abstracts into which are woven many references to the more important published articles on the point in question.

An especially valuable feature of the book is an alphabetically arranged compilation of 929 bibliographic references which Doctor Przibram cites in the text. These references deal largely with highly specialized aspects of the general topic and are intended to serve as guides to the reader for fuller development of the subject.

Verfärbung und Lumineszenz is written in relatively uncomplicated German and in a style that is simple, clear and concise. Although only 275 pages long, it covers adequately, in summary form at least, the more important of the multitudinous theoretical, experimental and applied phases of these closely allied topics. Doctor Przibram's synthesis should prove to be a valuable summary for ready reference in the hands of students and research workers in the field of mineral physics. The scope of the book and its systematic presentation of the matter suggest that it would serve as a fine textbook on the subject for those who can read simple German moderately well provided that it were supplemented by the indicated reference material either in class lectures or in outside reading. Much of the book will find an interested audience in advanced workers in mineralogy, economic geology and petrology who are concerned with details of interpretation of the formation of minerals and ores and petrogenesis.

Many readers may find that $8.25 is a high price to pay for a 275-page book in spite of the fact that it is very legibly printed on high quality paper with semi-matte finish and contains many excellent figures and tables. Purchasers of this volume will undoubtedly choose to make the investment largely on the basis of its broad coverage of the topic, its orderly exposition, and its large and critically evaluated bibliography.

REV. JAMES W. SKEHAN, S.J.

The Geology of Ireland, an Introduction; by J. K. CHARLESWORTH. P. xvi, 276; 99 figs., 21 pls. London, 1953 (Oliver and Boyd, 25 *s*).— Professor Charlesworth's *Geology of Ireland* is an introductory textbook of historical geology, illustrated almost entirely from Irish rocks and localities. As Ireland's geological history is nearly as full as England's, especially in its Paleozoic and Quarternary chapters, a well-connected story can be made. The book is written for first-year students of geology, and in its 8-page introduction it attempts to cover the physical geology and petrology that they will need; actually, however, the level of treatment is such that they would probably profit more from this book after a standard course or textbook in physical geology.

Because the book's aim is elementary instruction, the foreign geologist interested in Ireland's geology will not find it a regional handbook, but he will be able to glean much from it nonetheless, particularly if he first makes himself familiar with Irish geography. The chapters on the Tertiary and Quaternary history are especially complete, making about half the book. A selected bibliography is provided, and black and white maps scattered through the book cover the four quarters of the island and also in more detail localities of special interest. The photographs of Irish scenery are very fine and especially to be commended.

JOHN RODGERS

Regionalna Geologia Polski, Tom 1, Karpaty (Zeszit 1, Stratygrafia; Zeszit 2, Tektonika); edited by M. KSIAZKIEWICZ. Krakow, 1951, 1953 (Polskie Towarzystwo Geologiczne, Ulica Sw. Anny 6).—The Polish Geological Society has launched a regional geology series comparable to the series British Regional Geology and Géologie régionale de la France. The first volume, in two parts, deals with the Polish Carpathian Mountains; it is written in Polish, which will make the material much less accessible to geologists elsewhere. Students of regional geology will be thankful, however, to have it available.

JOHN RODGERS

English Rock Terms; by W. J. ARKELL and S. I. TOMKEIEFF. P. xx, 139. London and New York, 1953 (Oxford University Press, $4.25).—This pocket volume is a dictionary of the local (non-geographic) terms used by British miners, quarrymen, and geologists to describe the various rocks and strata with which they deal. The science of geology has taken a great many of its basic technical terms from just such local usage, and it is very interesting to have this survey of the still abounding reservoir from which they were drawn. The book will be a valuable addition to the growing list of special-purpose geological dictionaries.

JOHN RODGERS

Historical Aspects of Organic Evolution; by P. G. FOTHERGILL. P. xvii, 427. New York, 1953 (Philosophical Library, $6.00).—This is a very odd book. It apparently grew out of a controversy started by the author, who is a botanist, evolutionist and Roman Catholic, in the *Catholic Herald*. The results of this controversy suggested that an historical approach to evolution

would be useful and interesting. On the whole, the earlier part of the history is fairly conventional. The mediaeval period, which the author might reasonably have made much of, is dismissed in one and a half pages, with no discussion of the very interesting difficulties that presented themselves to Albertus Magnus when he considered the place of apes in the living world. The modern post-Darwinian statement which occupies half the book is a curiously uneven production. A great deal of space is given to Lamarckian experiments; the evidence for and against the inheritance of acquired characters has not recently been set out at such lengths in western writing, but there is no mention of Michurin or Lysenko, who surely belong to history, if not to science.

Of the work of Kammerer, only the experiments on *Salamandra* are mentioned in the text, and there is no account of the curious controversy that occurred about the alleged faked pad on the foreleg of *Alytes*, which the present reviewer has reason to think was never properly cleared up. It is perhaps characteristic of the book that the reader is referred for a modern discussion of Lamarckism to an article and a series of letters published over twenty years ago.

There is a great mass of genetic and cytological data given but practically no mention of modern field studies on evolution. E. B. Ford alone of the workers in this area is given his rightful place. Ernst Mayr appears in the bibliography but not elsewhere. David Lack and G. F. Gause make no entrance at all.

In spite of manifest deficiencies as a general text, the book has a definite value as a guide to some of the sterile by-paths of evolutionary biology during the first third of the present century, and will be useful as such to the future historian of the period.

G. E. HUTCHINSON

How Animals Move; by JAMES GRAY. P. xii, 114; 52 figs., 15 pls. New York, 1953 (Cambridge University Press, $3.00).—Readers who are familiar with Professor James Gray's research over the last 20 years will be acquainted with the long series of fascinating observations and analyses of the locomotion of animals made by him and his colleagues. Approached mainly from the point of view of biomechanics, this work has brilliantly elucidated the basic factors involved in everything from the creeping of earthworms to the gait of quadruped mammals. Now it has all been reviewed in this small book derived from six Christmas lectures for children delivered by Professor Gray at the Royal Institution. Although the early pages may seem to the adult reader somewhat obviously directed at the author's original audience, subsequent sections are mainly free of this attitude. For a brief and easily readable account of this field of experimental biology the book can be highly recommended to the general reader. Many excellent photographs, as well as figures from the original research data, provide an important addition to the text, although a number of the rather heavy-handed additional illustrations apparently drawn for the lectures may be questioned in this respect. Unfortunately, there are no references cited nor suggested additional reading.

TALBOT H. WATERMAN

The Major Features of Evolution; by G. G. Simpson. New York, 1953 (Columbia University Press, $7.50).

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